OIL FIELDS IN THE UNITED STATES

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BY

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PREFACE

At the present time, there is no book in print which describes in a scientific way all the oil fields of the United States and which aims to set before the student all the geological details of every important area. There are good books in which the principles of petroleum geology are discussed and in which specific oil fields are described by way of illustration. There are books which describe the oil fields of a decade ago in a manner which takes full advantage of the information then available. Oil fields have multiplied in the last ten years, however, and the literature has multiplied even more rapidly. The student of today who is preparing himself for the career of petroleum geologist, therefore, finds the details which he needs for a good perspective scattered through the files of magazines and of state and federal publications. The professional geologist who wishes to keep abreast of his subject finds himself handicapped, because the very nature of his work keeps him away from libraries where he might have access to the current literature. The executive of an oil company, who is eager to widen his knowledge on every phase of the company's operations, is unable to read all the literature because he lacks time. For all these, a book is needed that is complete and up to date.

During the last six years the author has had the pleasure of teaching petroleum geology to college students (four years at the University of Michigan and two years at the University of Wichita). In preparing his lectures for these courses, he searched the literature and brought together the instructive details of every district and every field. These details have been augmented and changed from time to time until they constitute at present all the essential facts regarding the occurrence of oil in the United States.

In making a selection from published facts, the author has been constantly guided by his own field experience which extends over a period of 15 years. Beginning in 1913 in the oil fields of western Pennsylvania, the summer field seasons during the ensu-

ing five years were spent in New York, Pennsylvania, Ohio, Kentucky, and Indiana. From 1918 to 1923, the author's entire time was spent in field investigations in the capacity of field geologist for two of the largest petroleum companies in the industry. During these years, a first-hand knowledge of the oil fields of Kansas, Oklahoma, Texas, Colorado, Wyoming, and California was obtained. Considerable time was also spent in Mexico and Alaska. In some of these areas, intensive detailed geological work was carried on, while in others the work was more of a reconnaissance nature. On the basis of this field experience, the author feels that he has been able to introduce considerable material which has not been printed elsewhere. It has also enabled him to evaluate the published data more critically and to select those details which will be most helpful to the student, as well as those which will be most enlightening to the professional geologist and to the oil-company executive.

In building a framework for the numerous details brought together in this book, the author has adopted a new basis of classification, which will be called the "tectonic classification." Oil fields have a relationship with each other which is controlled by the large structural features of our continental mass. These large structural features, or tectonic elements, are, therefore, used as a basis for the grouping of the scattered fields of the United States into petroliferous provinces. Each province forms a natural unit; but, in some cases, these units must be subdivided on the basis of structural features of subordinate rank within the province. Such subdivisions are called "districts."

With the tectonic setting as a background, the essential details of the stratigraphy in each province and in each district are treated at length. Equal emphasis is given to the peculiar structural conditions which have controlled the accumulation of oil and gas in each province and district as well as in certain typical fields and pools. The nature, thickness, and correlation of the oil horizons have been given as much space as these important topics warrant. Other less scientific details, such as the history of development, production statistics, first causes for development, and gravity of the oil produced, are all systematically taken up, in order to make the picture complete. The most helpful articles and papers that refer to the fields in each province or district are given in a selected bibliography appended to each chapter. These articles are arranged according to the date of

publication, as far as possible, inasmuch as the more recent articles frequently contradict, or at least add to, the information contained in previous publications. Another feature which will be appreciated is the tables of oil horizons and stratigraphic sequences in each district and each province arranged in a uniform manner, with a systematic nomenclature for the stratigraphic units.

The illustrations are carefully chosen and represent the best that can be found. They are maps and diagrams prepared by geologists who are particularly well informed on the characteristics of individual areas. Most of them have been taken from the *Bulletin* of the American Association of Petroleum Geologists. The author wishes to express his thanks to all who have been kind enough to permit the reproduction of such maps and diagrams. In each case, he has given credit to the proper authority for illustrations used in the book.

The author also wishes to acknowledge his indebtedness to his many friends in the American Association of Petroleum Geologists, some of whom have read portions of the manuscript and many of whom have contributed information of various kinds in written or oral form.

WALTER A. VER WIEBE.

WICHITA, KAN.,
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CONTENTS

CHAPTER VII

CHAPTER VIII

CHAPTER IX

CHAPTER X

CHAPTER XI

OIL FIELDS IN THE UNITED STATES

CHAPTER I

INTRODUCTION

The oil fields of the United States are remarkable because the annual production from them exceeds that of any other nation by a wide margin. They are also remarkable for another reason, and, to the person who is interested in the occurrence of petroleum in the world, the second reason is the more important. That is the fact that the oil fields of the United States are infinitely varied and illustrate practically every important set of conditions under which oil occurs anywhere in the world. Not only do they furnish examples of all types of structural features which trap oil and produce accumulations of commercial importance, but the stratigraphic range of occurrence is unequalled elsewhere. In the more subordinate details, such as the lithologic character and peculiarities of the reservoir rocks, the range in thickness and areal extent of the producing horizons, the evidence of the influence of metamorphism on petroliferous strata, etc., examples may be found to illustrate every variation. A complete analysis of all characteristics of the oil fields of the United States, therefore, should lead us to a better understanding of the more difficult problems of petroleum geology such as the origin, migration, and accumulation of petroleum.

Geographic Distribution.—Oil fields are rather widely distributed over the whole extent of the United States. In the East they appear in New York, Pennsylvania, West Virginia, Ohio, Kentucky, and Tennessee. In the Mississippi drainage basin, Indiana, Illinois, Arkansas, Louisiana, Texas, New Mexico, Oklahoma, and Kansas, all have important fields. In the same basin, but separated from the others, Montana, Wyoming, and Colorado are responsible for large quantities of petroleum

annually. In the West, California is the only state in the producing column, but it equals a good many of the Eastern states in total production. A few other states have small or relatively unimportant fields at present, but promise to become more prominent in the future. Among these Michigan stands out as the state with the greatest possibilities, while Utah Alabama, Mississippi, and a few others may have some surprises in store for the oil fraternity.

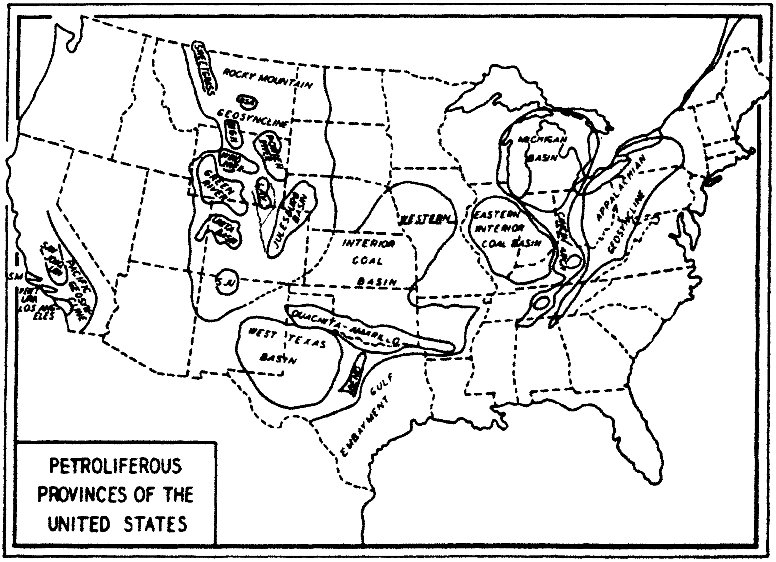

FIG. 1.—Map of the United States showing petroliferous provinces.

Tectonic Classification.—Up to the present, it has been customary to group the oil fields of the United States more or less arbitrarily in a geographic manner. Thus, we have become accustomed to such names as the Mid-continent area, the Appalachian area, the Rocky Mountain area, etc. The reason for this lies partly in the fact that development was gradual and the full significance of the relationship between somewhat isolated and scattered pools did not become apparent until recently. With the intensive campaign of geological exploration, which has been so successful during the last decade, has come a much clearer understanding of the probable areal extent of our oil fields and their relation to the large structural features of the continental mass. Thus, it has become apparent that the

architecture of the continent has exercized a controlling influence over the distribution of oil-producing areas.

It is entirely logical that this correspondence should exist. In certain parts of the great basins which were present for a long period of time on our continent (especially the geosynclines), conditions of sedimentation were such that great thicknesses of organic matter accumulated. The most likely areas for such accumulations were in shallow waters relatively near shore and in zones or belts where climatic conditions of that time encouraged luxuriant plant growth. Such areas are to be sought around the peripheral portion of the geosynclines and the smaller basins. Subsequent changes of a biochemical and a mechanical nature produced oil which migrated and accumulated either concomitantly or later in various kinds of traps within the same areas or near by. Under exceptional conditions of migration, the oil accumulated in a geanticline between two basins, as in the case of the Cincinnati geanticline.

Regions in which the petroleum accumulations are related genetically and in which the geologic surroundings are closely similar were called "petroliferous provinces" by Woodruff.[1] Schuchert,[2] in a discussion of this article, classifies the continental area into three categories. The areas impossible for petroliferous rocks are those in which (*a*) igneous rocks, (*b*) pre-Cambrian strata, (*c*) decidedly folded mountain tracts older than Cretaceous, (*d*) regionally metamorphosed rocks, or (*e*) continental or fresh-water deposits, predominate. Possible petroliferous areas are those in which (*a*) highly folded marine or brackish water, strata, younger than the Jurassic, (*b*) gently folded Cambrian and Ordovician strata, (*c*) saline, or arid climate, lake deposits occur. The petroliferous areas are (*a*) those in which marine and brackish water strata younger than the Ordovician system appear, or (*b*) all marine strata which are roughly within 100 miles of former lands. No important exceptions to Schuchert's generalizations have been found since 1919 and it is not likely that any will be found.

Tectonic Elements in the United States.—The continental area which we now call North America has undergone great

[1] WOODRUFF, E. G., Petroliferous provinces, A.I.M.E. *Bull.* 150, pp. 907–912, 1919.

[2] SCHUCHERT, CHARLES, Petroliferous provinces, A.I.M.E. *Bull.* 155, pp. 3059–3060, 1919.

changes during geologic time. Where once subsiding basins existed, we now find towering mountains and where mountains existed in the past we find low plains or plateaus. In a general way, there has been continuous growth from the nucleus in east central Canada (the Canadian shield or Laurentia) to the present broad expanse of land. The tectonic elements which exist today, therefore, are not the same as those of some geologic period in the past. It is taken for granted however, that the names used below are sufficiently familiar to the reader so that he will fit each into its proper span of geologic time.[1]

The best-known tectonic element on the continent is the Appalachian geosyncline. It existed from pre-Cambrian time until the end of the Paleozoic era, but its borders and outlines changed considerably during that time. Until at least the middle of the Ordovician period, it merged with the area west of the Cincinnati anticline which has been called the Mississippian Sea. From Ordovician time to the end of the Permian period its borders were more stable and it included a long, narrow trough, or group of troughs, west of Appalachia extending from Alabama to eastern New York. The troughs were at no time deep, but by subsidence allowed conditions for the generation of petroleum to exist continuously from Ordovician to Permian times. Hence the areas included in the Appalachian geosyncline should be considered one petroliferous province.

The basins and geosynclines west of the Appalachian geosyncline are less well known. In Michigan, a nearly circular basin existed from Ordovician to Permian times. Farther southwest a somewhat more elongated basin existed during approximately the same time which has been named the Eastern Interior coal basin (see Fig. 47). The next basin to the west is a very large one and has been named the Rocky Mountain geosyncline, and this in turn may be considered but a part of a still larger basin called the Cordilleran geosyncline. The latter extended approximately from the longitude of the present Mississippi River as far west as the land mass of Monzonia and from the Arctic Ocean on the north into Mexico on the south. During middle Paleozoic time, there were indications of a separation into two major basins, but this separation did not become complete or definite until about the close of the Jurassic period when the Cordilleran

[1] In this connection consult Charles Schuchert, Paleogeography of North America, *Bull.* Geol. Soc. Am., **20**, 1908.

Intermontane geanticline was formed. Thereafter, the eastern portion became independent as the Rocky Mountain geosyncline and existed until the close of the Cretaceous period, while the western portion, called the Pacific geosyncline persisted from the Jurassic well into the Tertiary period.

In the southern part of our country, there are two basins which have not been described as well as the basins farther north. One of these is the Mississippi Embayment, or Gulf Embayment, geosyncline. It is a portion of the present Gulf of Mexico and may have been in existence since pre-Cambrian time, although there is much evidence which indicates that it began its history during the Comanchean period. The other is a basin in western Texas which has been called the "Permian basin" or the "West Texas basin."

The tectonic elements described above may be called negative elements, because during the time of their existence they had a tendency to subside with reference to surrounding areas. Whereas they are more important from the standpoint of localizing petroliferous areas, yet some of the positive tectonic elements also have oil fields associated with them and must, therefore, receive consideration. The best-known positive element is the Cincinnati anticline (also called the Cincinnati arch and the Cincinnati geanticline). It is fully described in Chapter III, and Fig. 36, on page 94, shows its location. It may be considered the dividing ridge between the Appalachian geosyncline and the Eastern Interior coal basin. Another similar dividing ridge between two basins is the Ouachita-Amarillo Mountain ridge. This positive element begins in central Arkansas and trends nearly west through southern Oklahoma into the Panhandle of Texas, where the buried mountain range called the Amarillo Mountains constitutes its western limit. It separates the oil fields of the Western Interior coal basin province from those of the Gulf Embayment province and from the West Texas Basin province. Running nearly at right angles to this positive element is another similar one which has been named the Bend arch. The latter is located in north central Texas and separates the Gulf Embayment province from the West Texas province.

Petroliferous Provinces.—In succeeding pages of this book, it will be shown that the oil fields of the United States group themselves naturally around the borders of the great basins or

TABLE OF PETROLIFEROUS PROVINCES

Province	Districts	States involved
Appalachian geosyncline		New York, Pennsylvania, West Virginia, Eastern Ohio, Eastern Kentucky
Cincinnati arch	Lima-Indiana	Western Ohio, Eastern Indiana
	Cumberland Saddle	South-central Kentucky, Tennessee
	Alabama-Mississippi	Alabama, Mississippi
Eastern Interior coal basin		Northwestern Kentucky, Illinois, Indiana (southwestern)
Michigan basin		Michigan
Western Interior coal basin		Kansas, Northern Oklahoma
Ouachita-Amarillo Mountains	Arbuckle-Wichita	Southern Oklahoma
	Red River Uplift	North-central Texas
	Amarillo Mountain	Texas Panhandle
Bend arch		North-central Texas
Gulf embayment	Balcones fault	Eastern Texas
	Reynosa escarpment	Southern Texas
	Sabine and Ouachita uplifts	Northern Louisiana, Southern Arkansas
	Salt dome	Southern Texas, Southern Louisiana
West Texas basin		West Texas, Eastern New Mexico
Rocky Mountain geosyncline	Big Horn basin	Wyoming, Montana
	Wind River basin	Wyoming
	Green River basin	Wyoming, Northwestern Colorado
	Laramie basin	Wyoming
	Powder River basin	Wyoming
	Sweetgrass arch	Montana
	Big Snowy anticlinorium	Montana
	Julesburg basin	Colorado
	Uinta basin	Western Colorado
	San Juan basin	Northwestern New Mexico
		Utah
Pacific geosyncline	San Joaquin Valley	California
	Santa Maria	California
	Ventura	California
	Los Angeles basin	California

negative tectonic elements. In some cases, they occcur upon, or closely adjacent to, the positive elements between the basins. It seems appropriate, therefore, to name the provinces after the tectonic element with which they are most closely associated.

This system of classifying the fields has been followed out with one or two exceptions. For instance, the east side of the Rocky Mountain geosyncline has fields which are so different from those of the west side that two provinces were established for that reason. One of these is called the Western Interior Coal Basin province and the other the Rocky Mountain Geosyncline province. Both of these names suggest the location of the fields immediately and are not inconsistent with the tectonic classification.[1]

In some provinces, a further subordinate grouping is possible on the basis of structural conditions which separate a province into a number of individual, distinctive units. These units are called "districts." In the Gulf Embayment province, for instance there are four districts. Two of these may soon merge to form one (Balcones Fault district and Reynosa Escarpment district), because the characteristics of both are similar and new fields are being discovered between them which will serve to link them together. The other two districts of this province are so different in their nature that a distinction will always be necessary. The Rocky Mountain Geosyncline province is divided into districts each one of which is a small basin and sometimes separated from the others by great distances. Yet all these districts have certain characteristics in common so that they should be grouped together. The same may be said of the four districts in the Pacific Geosyncline province.

Within a district there may be one or more pools or fields. The words *field* and *pool* are used more or less interchangeably in the literature. However, the author has endeavored to use them in a different way. Whenever possible the word *field* has been used to designate a rather large area in which a number of pools are found. The word *pool* has been used only when the smallest unit into which a petroliferous area could be divided is referred to. Thus a number of pools ordinarily make up a field and as a rule there are a number of fields in each district.

Stratigraphic Distribution.—The stratigraphic distribution of petroleum in the United States is very great and much greater than in any other country of the world.

In a general way the age of the petroliferous strata increases from west to east and from south to northeast. Tertiary rocks produce the oil on the Pacific coast and are important

[1] For details consult article by author in *Bull.* A.A.P.G., **13** (No. 5), 409.

also in the area bordering the Gulf of Mexico. In the Rocky Mountain area the Cretaceous rocks take precedence and a little production comes from Paleozoic rocks. In the Mid-continent area the Paleozoic rocks, especially the Pennsylvanian and Permian strata, become the important producing strata. (Recently the Ordovician rocks in that part of the country have begun to take a leading position.) Farther east in the fields of western Indiana and Illinois, the Pennsylvanian rocks are most important, but Mississippian rocks assume some importance. In the northeastern part of the country the older Paleozoic systems produce the oil and in a large part of the Appalachian region the Devonian rocks are the most prolific source of petroleum. The Silurian strata are also very important in that region, while the Ordovician rocks are large producers chiefly in Ohio and Kentucky. In New York, even the Cambrian strata are productive, but up to date only gas has been found as low as this in the section.

Nomenclature for Stratigraphic Units.—At the Paris meeting of the International Geological Congress, held in 1900, the following names to indicate rank of units of time and of strata were adopted:

Units of Time	Strata Units
Era	Group
Period	System
Epoch	Series
Age	Stage
Phase	Zone

In the United States, a brave attempt has been made by many of our leading geologists to adhere to this set of names, but on the whole there is a pitiful lack of uniformity. Some of the names are used quite consistently as, for instance, *era* and *period* for time units, and *system* and *series* for strata units. The other names are entirely neglected or else used in the wrong way. An exception to this statement should be made in the case of the name *epoch*, since that term is used by a good many writers as the time equivalent for a series. The use of the term *group* as the strata equivalent of an epoch or instead of the term *series* has a very wide use. It is also used to a large extent instead of the term *stage*, that is for subdivisions of a series of rocks. Instead of the terms *stage* and *zone* there seems to be a

tendency to use the term *member.* The term *formation* is most used and it is used in the widest sense. It may be used instead of *stage, series* or even *system* as well as instead of the name *zone.* In order to preserve uniformity in this book the following terminology has been adopted and it has been followed out wherever direct quotations from other works are not involved.

Time Units	Strata Units
Era	Group
Period	System
Epoch	Series
	Formation
	Member

The Geologic Column.—According to the most commonly accepted usage, the geologic column (begining with the Cambrian) has 16 periods or systems. They are delimited on the basis of diastrophic conditions which are world wide. These systems belong to three groups (eras) which are larger units and are delimited by world events of outstanding magnitude. Usually the eras are brought to a close by extensive orogenic movements and times of long-continued emergence. Schuchert[1] prepared a chart of curves showing the amount in square miles of the inundations on the North American continent from the begining of Cambrian time. These curves show 17 lows (or inundations) separated from one another by as many highs, or emergent periods. On the basis of the splendid paleogeographic maps he prepared and the diastrophism postulated by them, he suggests a new classification in which there are 4 eras and 18 periods. These are placed side by side with those of the old classification in the table on page 10.

The author believes that the new classification rests on a sound scientific foundation and will ultimately be adopted either in its present form or with but slight modifications. The old classification is more familiar to the reader at present, however, and will be used in this book. The only place where the contents of the succeeding pages would fit the new classification better than the old is in the subdivision of the old Ordovician into Canadic, Ordovicic and Cincinnatic.

[1] Schuchert, Charles, Paleogeography of North America, *Bull.* Geol. Soc. Am., **20**, Plate 101, 1908.

Old Classification		New Classification	
Eras	Periods	Periods	Eras
	Pleistocene		
	Pliocene	Neogenic	
Cenozoic	Miocene		Neozoic
	Oligocene		
	Eocene	Eogenic	
	Cretaceous	Cretacic	
	Comanchean	Comanchic	
Mesozoic			Mesozoic
	Jurassic		
		Triassic-Jurassic.	
	Triassic		
	Permian	Permic	
	Pennsylvanian	Pennsylvanic	
		Tennesseeic	
	Mississippian		Neopaleozoic
		Mississippic	
	Devonian	Devonic	
Paleozoic	Silurian	Siluric	
		Cincinnatic	
	Ordovician	Ordovicic	
		Canadic	
			Paleozoic
		Ozarkic	
	Cambrian	Acadic	
		Georgic	

Reservoir Rocks.—Petroleum is most commonly found in sandstones or sands. Conglomerates are second in importance, while limestones rank in third place and shales last. Rarely other kinds of rock contain oil. Altered igneous rocks, often called serpentine, produce commercial quantities of oil in the Balcones Fault district of the Gulf Embayment province. In the Conejo pool of the Ventura district of the Pacific Geosyncline province, oil is found in a basalt agglomerate. The ideal characteristic of a reservoir rock is large pore space. For that reason, conglomerates come closest to the ideal reservoir. Limestones may contain much larger openings, but the production peculiarities and water difficulties which result from that condition make limestones less desirable. By far the most oil comes from sandstones and in these the pore space varies from nearly nothing to almost 40 per cent. The size of the grain as

well as the amount of compaction influence the amount of pore space in an unconsolidated sandstone. Schlichter[1] in his classical experiments, has found that the maximum pore space possible in a sandstone consisting of spherical grains packed as closely as possible, is about 26 per cent by volume. Many determinations made in all parts of the country on building sandstones as well as sandstones from deep wells show an average porosity of about 16 or 17 per cent. A higher pore space than the theoretical one may be obtained by angularity of grain and loose packing, while a smaller one is due to cementing material and difference in size of grain. The presence of clay particles which may be considered a cementing material, lowers the pore space greatly.

In some parts of the United States, limestones are very large producers of petroleum. In the fields of the Cincinnati Arch province this is particularly true. The most important limestone horizons in this country are the Trenton limestone of Ordovician age, the Onondaga limestone of Devonian age, the "Siliceous lime" of Ordovician age and the "Big Lime" of the West Texas basin which is of Permian age. The porosity in limestone may be produced by solution when the limestone comes within the sphere of action of circulating ground waters during a period of erosion. It may also be produced by dolomitization, which means that the calcium carbonate of the original rock has been replaced by magnesium carbonate. This change involves a change in volume which may reach as large a figure as 12 per cent.

Shales are rarely the immediate source of oil in commercial quantities. A number of fields are producing or have produced considerable amounts of oil, however, from openings in shales. Among these the Florence pool in eastern Colorado is the most important. A few of the Wyoming pools, as for instance the Teapot Dome pool, have produced small amounts of oil from shales.

Cap Rocks.—Besides a porous reservoir stratum, another necessary factor in an oil pool seems to be a covering stratum which is impervious and therefore prevents migration of fluids. The very fine texture of clays and shales makes these rocks an ideal kind of rock for the purpose. In some fields, cap rock,

[1] Schlichter, C. S., Theoretical investigation of the motion of underground water, *U. S. Geol. Survey*, *19th Ann. Rept.*, Pt. II, p. 310, 1899.

in this sense of the term, is not present. This is true to a large extent in the California oil fields. In a general way, it may be stated that those fields in which the producing horizon is of Paleozoic age, the covering strata are shales, while in those fields in which the producing horizon is of Cenozoic age, the covering strata are clays. In the intermediate case, in which the producing horizon is of Mesozoic age, both shales and clays occur. Locally, marls, chalk rocks, or limestones may serve in the capacity of cap rocks.

Oil Traps.—The third essential for an oil field is a structural condition in the producing horizon which can trap the oil and hold it indefinitely. I. C. White was the first to point out that an anticline furnishes an ideal trap for oil and his "anticlinal theory" later became the guiding star for petroleum geologists. The search for anticlines in Oklahoma and Kansas during the palmy days of oil geology proved the worth of this theory, for in numerous instances the correspondence between anticlines and the areal extent of oil pools was very close and convincing. Many anomalous situations were also discovered, however, in which anticlinal structure evidently had nothing to do with the accumulation of oil. Careful subsurface studies in recent years have shown that there are a great many possible oil traps and Clapp[1] has given us the best summary of these in his structural classification. He divides the oil traps into ten classes and some of these into subclasses. They are as follows:

Classification of Oil and Gas Structures

I. Aclinal or subaclinal structure.

II. Anticlinal and synclinal structures:

1. Anticlines standing alone. *Example:* Volcano anticline in West Virginia.
2. Well-defined anticlines alternating with synclines.
3. Broad geanticlinal folds. *Example:* Cincinnati anticline.
4. Overturned folds.
5. Lenticular nature of the sands.

III. Monoclinal structure:

1. Monoclinal noses. *Example:* Wooster pool in eastern Ohio.
2. Monoclinal ravines. *Example:* Western Pennsylvania in certain sands.

[1] Clapp, F. G., Revision of the structural classification of petroleum and natural-gas fields, *Bull.* Geol. Soc. Am., **28**, 553–602, 1917.

3. Structural terraces or "arrested anticlines." *Example:* Findlay field of northwestern Ohio.
4. Lenticular nature of the sands. *Example:* Glenn pool of northern Oklahoma.

IV. Quaquaversal structures or domes

1. Anticlinal bulges or "cross-anticlines." *Example:* Eldorado pool, Kansas.
2. Monoclinal bulges. *Example:* Osage County, Oklahoma.
3. Closed saline domes. *Example:* Salt domes of southern Texas.
4. Quaquaversal structure caused by volcanic plugs.
5. Perforated saline domes. *Example:* Southeastern Utah.

V. Contact of sedimentary with igneous rocks:

1. Contact of sedimentaries with volcanic plugs.
2. Contact of sedimentaries with dikes.
3. Contact of sedimentaries with intrusive beds.
4. Contact of sedimentaries with older igneous rocks.

VI. Strata dipping unconformably away from an old shore line. *Example:* Barton Arch, Kansas.

"II. Crevices of igneous rocks. *Example:* Copper Mountain, Fremont County, Wyoming.

II. Crevices of sedimentary rocks *Example:* Florence field of Colorado.

X. Faults:

1. Upthrow side. *Example.* Mexia pool, eastern Texas.
2. Downthrow side. *Example:* Balcones Fault district, Texas.
3. Overthrusts. *Example:* Santa Maria district, California.

X. Sealed in by bituminous deposits. *Example:* San Joaquin Valley district, California.

Migration and Accumulation of Oil.—It is not reasonable to believe that the oil found in pools of commercial importance was always there. It probably traveled some distance from its place of original generation or formation and accumulated because its further progress was barred by structural conditions or physicochemical conditions. When we attempt to describe the exact processes of migration and accumulation we are entering the realm of speculation. It is possible to imitate some of nature's processes in the laboratory and to ascertain in this manner what probably took place at some depth in the earth's crust, but certain factors enter into nature's work which cannot be reproduced above the surface. The most difficult factor of this kind whose value we cannot appreciate is the element of time. Other factors which are difficult to introduce into the

experiments are the conditions of pressure and temperature that probably exist at the depths where migration took place. Nevertheless, enough has been accomplished by experimentation to suggest a number of probabilities which no doubt come close to the actual processes. Some of these were worked out in an empirical manner on the basis of the laws of physics and chemistry and later proved by experiments. Others were discovered by closely watching the results of experiments in operation. Many ideas about migration and accumulation are merely hypotheses which still await proof.

When all has been written, it will probably be found that migration has been infinitely slow in most cases, but fairly rapid in some cases, also that it has taken place within relatively short distances in most parts of the country, but has covered great distances in a few districts or provinces. The fundamental fact of migration is probably best proved by the fact that oil is found separated from the gas and water which were first mixed with it. This is due to the forces of *gravity* and it determines the arrangement of the three fluids in a reservoir. The gas, being lightest, assumes the highest position available in the porous reservoir. The water, being heaviest, assumes the lowest position in the reservoir and the oil, being heavy also, but lighter than the water, takes up a position immediately above the water. Thus it happens that gas is always encountered in the highest part of the reservoir, but the oil and water are not necessarily found in adjacent parts of the reservoir.

Another motive force which may push oil and other fluids through porous rocks is the surface tension, or *capillarity*. The result of this force is to draw oil and water into small openings and pores of capillary size, regardless of the force of gravity (or perhaps it should be said, *in apparent violation* of the force of gravity). The rise of kerosene on a lamp wick illustrates the process. Since water has a surface tension which is nearly three times as great as that of oil, the pull on water is nearly three times as great as the pull on oil. Since the amount of capillary pull varies inversely as the size of the pore or tube, the water, therefore has a tendency to occupy the minute pores and displace the oil which may be in them. The oil, therefore, follows the line of least resistance when it takes up its position in the more porous parts of the reservoir. The gas which cannot be drawn into capillary spaces by surface tension goes into the

largest openings. Capillary openings in a reservoir rock vary in size from 0.5 millimeter to 0.0002 millimeter (for water). In larger pores or tubes, water will follow the ordinary laws of hydrostatics; in smaller pores or tubes, it remains permanently fixed. When oil and water which were originally present in a sandstone and a shale stratum adjacent to each other have rearranged themselves in accordance with capillarity, the water in the pores of the shale will make it impervious to further migration and the oil is confined to the sandstone.

Experiments performed in the laboratory to indicate the influence of capillarity do not reflect the true conditions in an oil-saturated zone beneath the surface. This is due to the fact that capillary attraction decreases when the temperature increases. Since the temperature rises in the earth's crust, this means that capillarity decreases with depth. Moreover, there is a difference in the rate of decrease for oil and water. For theoretical details regarding the importance of capillarity, the reader should consult the writings of Washburne[1] and for the results of experiments he should consult the writings of McCoy.[2]

The importance of *moving water* as a factor in the migration and accumulation of oil has been brought out by Munn[3] and more recently by Rich.[4] Water moving through porous rocks may carry oil with it even though the flow of the water is exceedingly slow. Artesian water which is under pressure because the aquifer is saturated with water below a certain level travels toward a point where it can escape. A good example of an aquifer in this country is the Dakota sandstone which underlies thousands of square miles in the western part of the Rocky Mountain geosyncline. Accumulation is thought to result in this case from the selective segregation of the oil and gas which have a tendency to work up toward the roof of the aquifer. When a favorable trap is encountered in the path of migration, the oil and gas will be left behind and will, therefore, accumulate in such traps.

[1] Washburne, Chestep, The capillary concentration of gas and oil, *Trans.* A.I.M.E., **50**, 829–842, 1914.

[2] See especially *Bull.* A.A.P.G., **10**, 1024–1033, 1926.

[3] Munn, M. J., The anticiinal and hydraulic theories of oil accumulation, *Econ. Geol.*, **4**, 509–529, 1909.

[4] Rich, J. L., Further notes on the hydraulic theory of oil migration and accumulation, *Bull.* A.A.P.G., **8**, 213–225, 1923.

The potency of *gas* as a *propulsive force* for the oil has also been brought out by several geologists.[1] Inasmuch as the gas in an oil pool is looked upon as the force which makes the oil flow from the wells, it does not seem unreasonable to attach a good deal of importance to it as a collecting force underground. Mills is inclined to attribute much importance to the presence of faults, because differential pressures are set up when faulting occurs and the rush of the gas to escape and bring about equilibrium takes oil toward the point of escape. Under such circumstances, migration and accumulation of oil are very rapid processes. One illuminating experiment described by Mills is the one in which he placed sand saturated with oil, water, and a fermenting liquid into a tightly stoppered bottle. When the cap was punctured after three days, the gas which had formed rushed toward the opening and brought with it much oil as well as water within a very few minutes time. Similar results were obtained in another experiment in which the plate-glass front of an experimental tank broke accidentally.

Finally, some measure of importance must be given to the suggestion of Daly that the pressure generated as a result of *diastrophic movements* may move oil through porous rocks. If it is considered that the problem has two aspects, the movement of oil from the original source rock to the reservoir rock and, secondly, the movement within the reservoir rock, then it may be found that Daly's suggestion applies most forcibly to the second. Experiments which attempt to show the relationship between pressure and oil movement from shale to sandstone have been attempted by several geologists, but they are not conclusive because the same results can be obtained without pressure by simple juxtaposition. After the oil has migrated to the reservoir rock, however, it is conceivable that diastrophic movements can overcome the inertia of the fluids and start a movement which will result in large accumulations.

Origin of Petroleum.—It is hoped that a careful compilation of data regarding each field in the United States, and especially an exposition of their peculiarities and similarities, will lead eventually to a better understanding of the difficult problems of migration, accumulation, and origin of petroleum. At

[1] See Johnson, R. W., The accumulation of oil and gas in sandstone. *Science* (new ser.), **35**, 458, 1912; Mills, R. Van A., Natural gas as a factor in oil migration and accumulation, *Bull.* A.A.P.G., **8**, 14–21, 1923.

present, we are quite in the dark as to the original condition of petroleum in the rocks and the chemical changes which have made it what it is. The weight of evidence which has been accumulated up to date seems to indicate that the organic thory for the origin of oil is nearer the truth than is the inorganic theory. Engler[1] has attempted to show that plant and animal remains decay in salt water first with an elimination of albumin and cellulose, and later of carbon dioxide and water from the fatty acids and esters leaving hydrocarbons of high molecular weight. Such material accumulated in quiet, swampy basins of large geosynclines of the past and may be the original mother material of crude petroleum. Black shales appear to have much material in them which is essentially similar, and yet it is difficult to conceive of any natural process by which it might be squeezed out of the shale and into a porous reservoir. It is not known, therefore, how it changed to the liquid form and when the change took place. The change of "kerogen" (as the source material has been called) to liquid petroleum has been produced by the application of heat. Field evidence, however, is lacking which would show that the necessary temperature of 450° had been reached in areas which are now petroliferous. To simplify the problem, it may be assumed that liquid hydrocarbons form in marine oozes and are buried with them and that the waxy kerogen now found in black shales is an alteration product produced when the sediments are consolidated. In that case, the common association of dark, bituminous shales with producing zones in oil fields would not mean that the shales had furnished the oil, but merely that they contain the oil which had not been previously confined in the reservoir strata.

Following this thought a little further, it might be assumed that differential subsidence, which would go on at the same time as further accumulation of sediment and consolidation, could produce the traps which hold the oil. Also, the amount of mechanical shifting of individual particles during this time might start and aid migration of the fluids in the sediments. In this manner, origin, migration, and accumulation would all take place more or less concomitantly and certainly very early in the history of a given set of strata.

[1] Engler, C., *Econ. Geol.*, **4**, 625.

Surface Indications of Petroleum.—In practically every district and every province of the oil fields of the United States, surface indications led to the first attempts to find oil by drilling. The oil spring near the city of Cuba in Allegany County, New York, was described by a Franciscan missionary in 1627. Fifty miles north of Cuba a gas seepage near Bloomfield was known to the early settlers as the "burning spring." Along the Allegheny River in western Pennsylvania, the small seepages of oil were the cause of the first successful oil well drilled in the United States by Colonel Drake. Similarly, the gas escaping along the Blanchard River in northwestern Ohio caused the early wells to be drilled in that part of the country. Oil exudations along the Wea River in eastern Kansas started development in the Mid-continent area. Gas seepages called attention to the salt domes of southern Texas and aroused the interest of Captain Lucas, whose unflagging zeal was finally rewarded by the first gusher drilled in the United States. Illustrations like this, in which oil or gas seepages led the way to drilling, might be cited in considerable number.

In California, a different type of surface indication aroused the attention of the oil producer. There small pools or lakes of tar occur, the largest one of which, called the "Brea" lake near Los Angeles, is described on page 561 in Chap. XI. Other large deposits of asphalt are known in Ventura County and along the west side of the San Joaquin Valley basin. Dikes or crevice fillings of hardened hydrocarbons are also present in California. In the eastern part of our country, such dikes are rare, but one dike 1 mile long and about 5 feet wide, in Ritchie County, West Virginia, was described by White. A few have been reported from south-central Oklahoma.

In the region of the Gulf coast where salt domes contain oil, it was soon found that sulphur at the surface, or sulphur springs or even salt water springs indicate a possible oil pool beneath. Another surface indication peculiar to that region is the presence of a low topographic mound. This is due to the growth of the salt mass with which the oil is associated.

Oil-field Maps.—When a district or area has been proved to contain oil and the characteristic structural conditions are known under which the oil occurs, that type of structure becomes a surface indication quite as valuable as a seepage and often more so. Thus, anticlines are so commonly the trap for oil pools that

they are sought out in many parts of the country. In some districts, surface faults are looked upon as possible guides for oil deposits.

Where rock outcrops are fairly numerous, it is possible to work out the detailed structure of the rocks and, inasmuch as

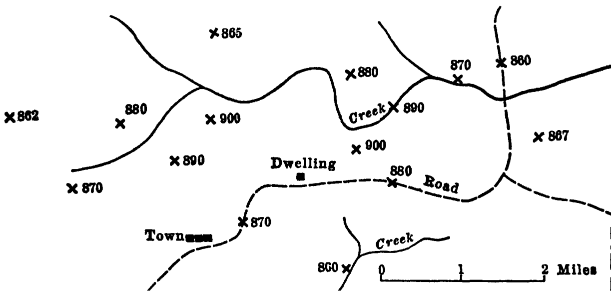

FIG. 2.—Sketch map showing elevation of the same stratum at different points, marked by crosses. (*After Gardner, Hager's "Practical Oil Geology."*)

the surface structure usually reflects the subsurface structure faithfully, at least to a certain depth, a map is prepared which shows the attitude of the strata. Figure 2 shows how the information secured by means of an alidade and plane table, is first plotted on a base map showing only location of points

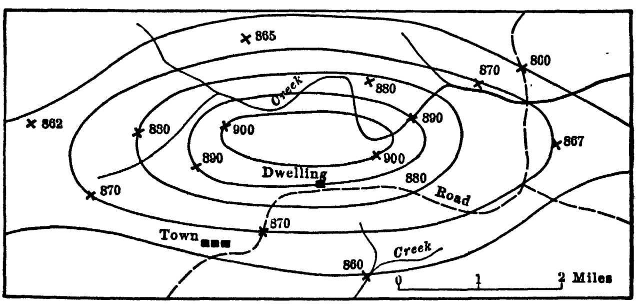

FIG. 3.—Sketch map showing elevations of same stratum at different points marked by crosses as in Fig. 2. The structure contours are drawn connecting points of equal elevation, thus outlining an elongated dome. (*After Gardner.*)

where elevations were secured with the elevation above some known datum plane. Figure 3 shows the same base map with contours drawn through all points having the same elevation. This map is usually referred to simply as a contour map. Figure 4 shows in cross-section how the rocks in the same area are

arched beneath the surface although the topography may be quite different.

In all petroliferous provinces of this country, the areas in which it is possible to prepare contour maps on the basis of surface outcrops have been studied intensively by geologists, and nearly every major oil company has maps for all areas that appear to have possibilities for production. In some provinces and in many districts, it is not possible to make a contour map from surface observations. Under those circumstances, elevations on some concealed stratum of rock are secured from the record of water wells, dry holes, or oil wells which show coal veins, salt layers, a red shale zone, or a similar recognizable datum

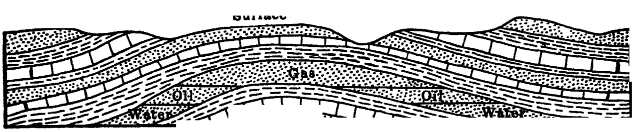

FIG. 4.—Lengthwise section of elongated dome shown in Fig. 3, vertical scale greatly exaggerated. (*After Gardner.*)

plane. In recent years, shallow holes have been drilled in many parts of the Mid-continent area, for the purpose of determining the attitude of some key rock. This is spoken of as "core drilling," from the fact that a small core of the formations penetrated by the drill is brought up and may be examined.

During the last few years, maps have also been made which show data that have to be translated into structural data before a structure contour map can be made. These maps are made with a torsion balance, a seismograph, or a magnetometer. Naturally, the information furnished by these instruments consists of physical data which may or may not correspond to rock structure. The torsion balance and seismograph have been found very valuable in the salt-dome fields of Texas and Louisiana. Over 30 new domes have been found through their use. The magnetometer has been used extensively in Kansas, Oklahoma, and Texas and the results so far have been satisfactory.

Production Statistics.—The production of oil in the whole world for the year 1929 amounted to nearly 1,500,000,000 barrels. Of this total, the United States produced about two-thirds, or 1,000,000,000 barrels. Venezuela, which ranked second produced less than one-tenth as much or 135,000,000 barrels. Since 1859,

the United States has produced slightly over 12,000,000,000 barrels. In 1929 Texas took the lead with a total of 298,-000,000 barrels followed by California with 292,000,000 barrels, Oklahoma coming in third place with 252,000,000 barrels. In previous years, California has been the leading state most of the time although occasionally it was exceeded by Oklahoma. The rise of Texas has been rapid, and if all wells in that state were allowed to flow freely, the production at present would exceed that of any other state. Production figures for the various provinces and districts in the United States are given in succeeding pages at the appropriate place in each chapter.

CHAPTER II

THE APPALACHIAN GEOSYNCLINE PROVINCE

The fields of the Appalachian geosyncline comprise a unit geologically and geographically. They are located in the states of New York, Pennsylvania, Ohio, West Virginia, and Kentucky.

The Tectonic Setting.—Because of the age of the fields in the Appalachian district and the great number of wells which have been drilled in various parts, we are unusually well acquainted with the stratigraphic succession and the major structural features therein. In order to visualise these structural features at the outset, it will be profitable to review briefly certain phases of the historical geology of this region. At the beginning of the Paleozoic era, a large land mass extended along what is now the Atlantic seaboard from New York to South Carolina. This land mass was named *Appalachia* by Dana (see Fig. 5). Its extent to the east is unknown, but probably it included what is now the shallow continental shelf. On the west, its limits changed slightly during Paleozoic time, but can be determined pretty accurately from a geologic map of the United States.

Formation of the Appalachian Geosyncline.—During the whole Paleozoic era, a narrow trough existed west of this land mass, reaching from eastern New York down into northwestern Georgia and northern Alabama. The water which filled the trough was shallow water, as evidenced by ripple marks, cross-bedding and similar features in nearly all horizons of the Paleozoic group. At some places, however, the thickness of rocks laid down in this trough is over 10,000 feet. The conclusion is reached, therefore, that the bottom of the trough gradually subsided about as fast as sand and mud were brought in by streams from the high land to the east, however—and this detail is very important to the petroleum geologist—the subsidence was not by any means uniform nor continuous. There were periods during which subsidence went on rapidly as, for example, during late Devonian time and during Pottsville time of the Penn-

sylvanian period. On both of these occasions, subsidence was rapid in the eastern part of the trough close to the land mass of

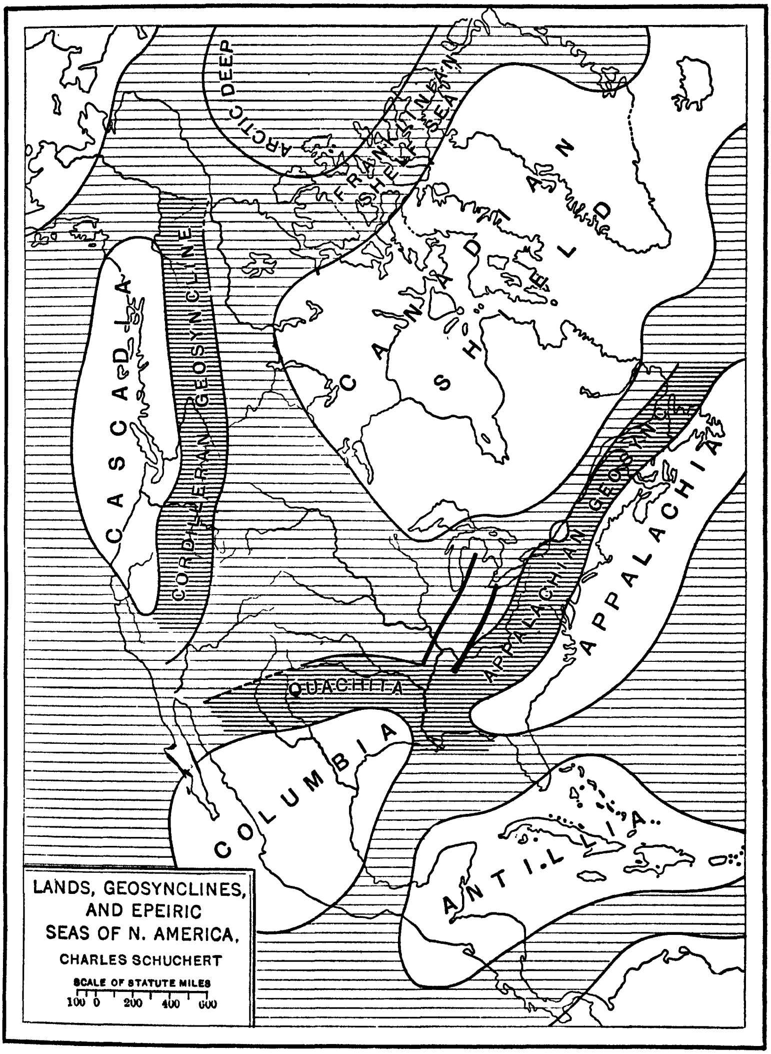

FIG. 5.—Generalized map of North America in Paleozoic time showing Appalachian geosyncline, etc. (*After Pirsson and Schuchert, "Textbook of Geology," p. 577. Courtesy of John Wiley and Sons.*)

Appalachia, and less rapid progressively toward the west. Consequently, the deposits laid down during late Devonian time

and during the Pottsville epoch become decidedly thinner from east to west.

Initial Anticlines.—During such periods of subsidence, all portions of the trough did not subside equally. Along certain lines running parallel to the long axis of the trough, narrow zones remained relatively higher than adjacent portions east

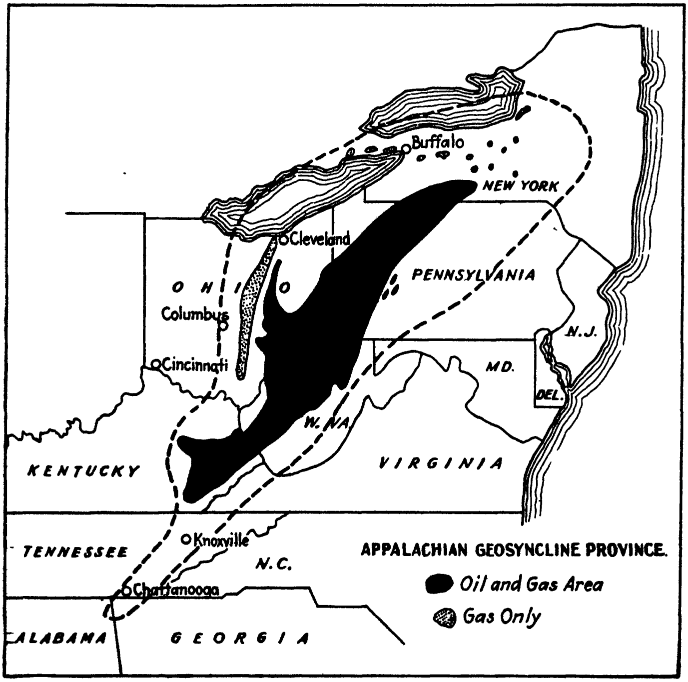

FIG. 6.—Appalachian geosyncline petroliferous province. Oil- and gas-producing areas in solid black and areas in which only gas is produced in stippled pattern.

and west. The differential subsidence produced anticlines with low initial dips which later may or may not have become accentuated by tangential thrust. A striking illustration of an anticline formed in this manner is the Cincinnati geanticline which, with its continuations, the Nashville dome and the arch through Ohio into Ontario, was produced in the latter part of the Ordovician period. This arch is usually thought of as forming the western side of the Appalachian geosyncline, however, and should, therefore, not be used as an illustration. It is very probable that the Chestnut Ridge anticline, the Volcano-Burning

Springs anticline (see Fig. 15), and the Cambridge anticline (see Fig. 25) are examples which belong to the class described.

Diastrophism.—During the long periods of the Paleozoic era, there were times when the lateral thrust from the land mass to the east of the Appalachian trough produced folds parallel to those previously formed. This was especially true in the eastern half of the trough and probably did not affect the western half of the trough. Toward the close of the Paleozoic era, during the Pennsylvanian and Permian periods, these times of powerful thrust came oftener and finally raised the sediments above the level of ocean waters. Erosion went on simultaneously with the folding and uparching of the strata so that it need not be assumed that the ancestral Appalachian Mountains were very high. The zone of highly folded sediments is clearly marked off from the zone of gently undulating sediments in the western part of the area. In the former, the great amount of metamorphism which resulted from the diastrophic movements is most delicately shown in the alteration of the Pennsylvanian swamp deposits.

Carbon Ratios.—In eastern Pennsylvania, some of the swamp deposits of carbonaceous materials were altered to anthracite with a very high carbon ratio. Farther west in the same state, as well as in West Virginia and Virginia, bituminous coal is now found which has also a high carbon ratio (of 60 per cent or more). David White was the first one to point out the relationship between the carbon ratios of coals and the existence of oil and gas pools. Inasmuch as we do not expect to find gas pools of commercial value in areas where the carbon ratio runs higher than about 65 per cent and oil pools in areas above 60 per cent, the eastern half of the Appalachian trough may be ruled out immediately. The area where it can logically be expected to find oil and gas accumulations, therefore, consists of the western half of the Appalachian trough. This area comprises southwestern New York, the western quarter of Pennsylvania, the eastern half of Ohio, the western two-thirds of West Virginia, and the eastern half of Kentucky.

Historical.—The first discovery of petroleum in the United States was made by the Franciscan missionary, Father Joseph de la Roche d'Aillon, in 1627, near the town of Cuba, Allegany County, New York. The priest's letter in which he described the "oil spring" was published in Sagard's "Histoire du Canada." The Seneca Indians, on whose territory the spring was found,

held it in high regard and in their treaties reserved it with a square mile of land. Fifty miles north of this seep there was a

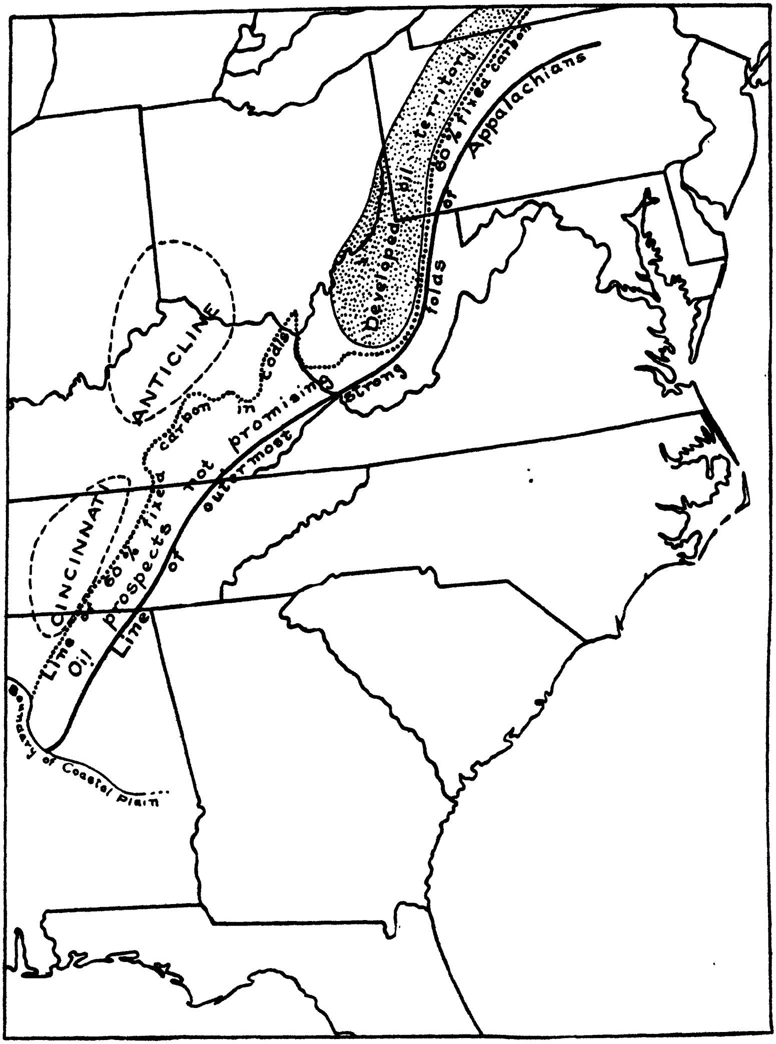

FIG. 7.—Map of the Appalachian region showing relation of developed oil fields to the 60 per cent line of fixed carbon in coals. (*After Fuller, Bull.* Geol. Soc. Am., **28**, 619.)

"burning spring" (gas seep near Bloomfield south of Rochester). In 1857, natives living near the oil seepage succeeded in drilling a hole to a depth of 450 feet at this spot, from which they secured

oil which they shipped in barrels to New York. The sand from which the oil exudes is the Chipmonk sand which produces oil in the Chipmonk field opened in 1896.

Ten years before the natives drilled for oil near the Cuba seepage, Thomas Kier leased a piece of land near Tarentum, Pa. upon which to drill for salt. In the process of boiling the brine from the wells, petroleum accumulated on the surface of the fluid. It was at first dumped into the canal nearby. Later it was burned, but this practice was forbidden. Because it was difficult to dispose of the mineral oil, Kier hit upon the idea of selling it for medicinal purposes. He also submitted samples of it to a Professor Booth, in Philadelphia, who advised him to distill it and use it as an illuminant. The experiment succeeded, and in a very short time the demand for the worthless mineral oil became insistent. A man by the name of Bissell conceived the idea of drilling for this substance and finally induced Col. E. L. Drake to undertake the task. The latter went to Tarentum and found a driller by the name of Billy Smith, who with his two sons came to the now historic spot, two miles south of the village of Titusville, Pa., to sink the first hole drilled for the express purpose of getting petroleum. The first well was successful at a depth of only 69 feet, producing about 20 barrels per day. A mad rush followed for the Oil Creek field, as it came to be known, so that by the end of 1860, or a year and four months later, the production amounted to half a million barrels. From this point, prospecting with the drill was carried on, especially to the south into Venango, Butler, Allegheny, Washington and Greene counties in Pennsylvania and on into southwestern Ohio and into West Virginia.

Stratigraphy.—The rock succession in the Appalachian geosyncline is very interesting. Every period from the Cambrian to the Permian is represented. The rocks of the first two systems are largely limestone, but the rocks of the later systems are mostly shales. Interbedded with the limestones and shales are sandstones of varying thickness. These sandstones appear in the section more abundantly toward the top. Here also may be noted many coal seams, the most important one of which is the Pittsburgh coal. It marks the base of the Monongahela series and, because of its thickness, uniformity in position, and wide distribution, has been adopted as the most reliable reference horizon. It is used in mapping surface structures and is also

used in constructing subsurface maps on deep-seated horizons. Above the Pittsburgh there are other coals which can be used for surface mapping in the Monongahela series of the Pennsylvanian system as well as in the Dunkard series of the Permian

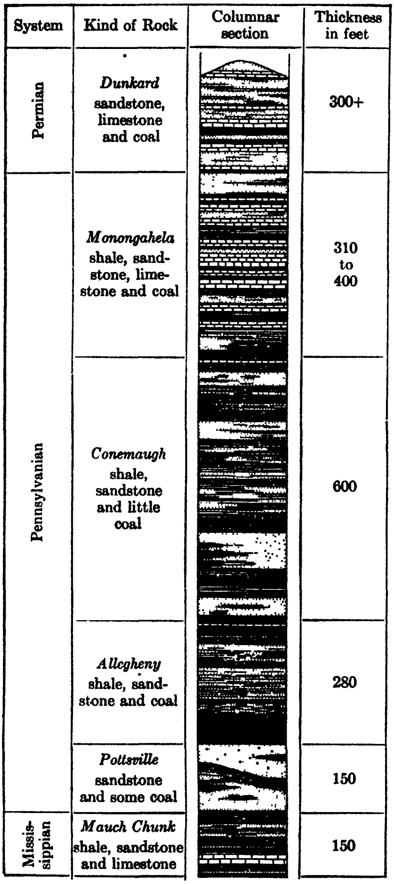

Fig. 8.—Geologic section in western Pennsylvania. (*After Campbell, U. S. Geol. Survey, Folio* 94.)

system. For subsurface mapping, the thick limestones are most reliable. One of these is commonly called the "Big Lime" by the drillers in western Pennsylvania and adjacent areas. It is the Greenbrier limestone of middle Mississippian age. This limestone has been correlated with the Maxville of Ohio. In central Ohio, a lower series of limestones is called the "Big Lime"

by the drillers. This is the Devonian "Corniferous" (Onondaga) limestone together with the underlying Silurian Niagara limestone. Finally, in some parts of the area, the Trenton limestone is reached and it forms a very good bed for correlation purposes.

Areal Geology.—The distribution of the rocks in the fields of the Appalachian geosyncline is shown on the map (Fig. 25 p. 68). It will be noted that the oldest rocks, the Cambrian and Ordovician systems, occur on the periphery of the area. Along the east side of the geosyncline, these systems crop out in long, narrow ribbons, due to the fact that there the rocks are standing

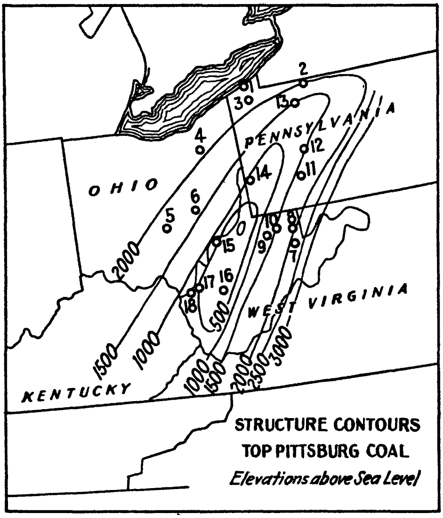

FIG. 9.—Structure of the Appalachian geosyncline. Contours drawn on top of Pittsburgh coal. Numbers refer to location of deep wells described on page 44. (*After J. French Robinson, Oil and Gas Journal.*)

nearly on end in long, parallel, eroded folds. On the west side of the area, they occur in large, broad, roughly ovate patches because there they project through the younger rocks where the crests of very flat domes have been dissected by erosion. Silurian, Devonian, and Mississippian rocks form more or less concentric bands within each other and within the older rocks. Toward the center and occupying by far the largest area are the rocks of Pennsylvanian age. Finally in the center and the deepest portion structurally of the great trough, at the intersection of three states, the Dunkard series crops out, which is believed by many to be of Permian age.

Tectonics.—The formation of the major controlling structural element in the eastern part of the United States, the Appalachian geosyncline, has been discussed. The map (Fig. 9) shows by contour lines that the deepest part of this trough lies in the northwestern part of West Virginia and more specifically in Wetzel County near Wileyville. Contours on the Pittsburgh coal show a drop of 2,000 feet from central Ohio to the lowest point and a drop of 3,000 feet from the edge of the Appalachian Mountains in eastern West Virginia. Contours on the Big Injun (top of Pocono formation) sand show a drop of nearly 2,700 feet in the same distance on the west side of the trough. The difference in the two sets of figures is due to a thickening of the formations from west to east or convergence from east to west. This convergence would be even more strikingly shown if sufficient data could be had from which to construct a contour map on the top of the Devonian limestone, since the thickening of the upper Devonian shales is at the rate of from 35 feet per mile in eastern Ohio to 50 feet per mile in western Pennsylvania.

Within the Appalachian trough are subordinate structures of great size and of major importance. Perhaps the most prominent one of these is the Burning Springs-Volcano-Eureka anticline. This fold lies in western West Virginia in Wirt, Ritchie, Wood, and Pleasants counties and crosses the Ohio River over into Washington County, Ohio. It is about 2 miles wide and has a series of domes on it one of which is 15 miles long, and has a closure of over 900 feet. The dip on both sides is steep, measuring 700 feet to the mile. When this is compared to the average regional dip of about 30 to 40 feet to the mile, it will be appreciated that the Volcano anticline is a very outstanding structure. Another remarkable feature about this anticline is its trend. The trend is nearly north and south, whereas practically all the other anticlines trend more nearly northeast and southwest.

Among the other anticlines which are important in West Virginia and southern Pennsylvania are the Arches Fork, the Warfield, the Murrysville, the Chestnut Ridge, and Laurel Ridge anticlines. Some of these are shown in Fig. 17. Between these anticlines, some of which can be traced for 50 miles or more, there are synclines. These, however, have received but scant attention because of the exaggerated importance attached to anticlines as the cause for oil accumulation.

Local Structure.—As might be expected, these anticlines and synclines are not always perfectly symmetrical. They are abundantly modified by terraces, noses, ravines, small domes, and basins. Good examples of these may be studied in the folios of the U. S. Geological Survey or in the *Bulletins* of the same survey. Folios 176, 177, and 178, will serve the purpose.

Oil Horizons.—There are probably more zones or horizons in the stratigraphic section of the Appalachian trough which produce oil or gas than in any other part of the world. The table on the next page shows exactly 56 individual strata which may contain oil or gas, or both. A few of these are limited to New York but the rest are found to be productive in the states farther south. By far the greater number are true sandstones, well consolidated, consisting of more or less rounded grains of quartz with an average porosity of perhaps 16 per cent. Some of them are well cemented and hard, others are more loosely cemented and called "soft" by the driller. Most of them are fine grained, but occasionally lenses of coarse-grained sandstones are reported, and even gravelly beds occur. They also vary in thickness within wide limits. The thickest is the Big Injun sand which varies from 50 to over 400 feet. The average thickness of all the sands is probably less than 25 feet. In addition to these sandstones, some of the limestones are found to be productive in certain places. This is true of the Greenbrier or Big Lime, and the Corniferous, the Niagara and the Trenton limestones. These limestones produce from porous zones which may be due to solution, dolomitization, or possibly other causes.

Considerable differences are to be noted in the uniformity and continuity of these horizons. The limestones, as might be expected, are quite uniform in thickness over considerable areas and have been traced entirely across the geosyncline. The sands are much more erratic. Two of them, however, stand out as exceptions. They are the Big Injun, found at the top of the Pocono, and the Berea, which is the basal sandstone of the same formation. Both of these can be traced across the geosyncline and are to be found over a very wide area north and south. The thickness of each varies from place to place to a certain degree, and occasionally they split into several sandstones with thin shale breaks, but normally they can be expected to appear in the well log at the proper horizon. The Clinton sand

TABLE OF OIL AND KEY HORIZONS IN APPALACHIAN

System	Formation	Driller's name		Geologist's name	Approximate thickness, feet	Interval to Pittsburgh coal, feet
Permian	Dunkard	Bluff sand		Waynesburg sandstone	60	390
Pennsylvanian	Monongahela	Waynesburg coal		Same	5	330
		Carrol sand	1	Uniontown sandstone		300
		Mapletown coal		Sewickley coal	6	110
		Pittsburgh coal		Same	10	0
	Conemaugh	Murphy sand	2	Morgantown sandstone	100	200
		Ames limestone		Same		260
		Little Dunkard or First Cow Run	3	Saltsburg sandstone	30	370
		Big Dunkard or Cow Run	4	Mahoning sandstone	100	500
	Allegheny	Connelsville coal		Upper Freeport	6	565
		Second Cow Run	5	Freeport sandstone		600
		Gas sand	6	Kittanning sandstone	70	700
		Vanport limestone		Same		780
	Pottsville	Johnson Run sand	7	Homewood sandstone		800
		First Salt sand	8	Conoquenessing	70	850
		Second Salt sand	9	Conoquenessing (lower)	90	940
		Third Salt sand	10	Sharon conglomerate	40	1,070
Mississippian	Mauch Chunk	Maxton sand (Cairo)	11		20	1,150
		Red Rock		Red shale	50	1,195
	Greenbrier	Little Lime		Greenbrier	5	1,195
		Pencil Cave		Greenbrier	5	1,200
		Big Lime	12	Greenbrier	50	1,205
	Pocono	Big Injun	13	Burgoon	300	1,255
		Keener (Ohio)	14	Logan sandstone	20	1,100
		Squaw	15	Black Hand	130	1,590
		Wier (West Virginia and Kentucky)	16		100	1,850
		Berea	17	Berea	40	1,840
Devonian	Catskill	Gants or Hundred-foot	18		30	1,930
		Fifty-foot	19		50	2,068
		Thirty-foot or Nineveh	20		35	2,035
		Snee sand	21		20	2,060
		Gordon Stray sand	22		40	2,100
		Gordon sand	23		20	2,175
		Fourth sand	24		20	2,225
		Fifth sand	25		30	2,290
		Bayard sand	26		10	2,390
		Bayard Stray sand	27		10	2,415
		Bayard Stray stray	28		15	2,435
	Chemung	Elisabeth sand	29		40	2,545
		First Warren sand	30		10	2,790
		Second Warren sand	31		15	2,850
		Third Warren sand	32		20	2,930
		Speechley Stray sand	33		15	3,050
		Speechley sand	34		15	3,120
		Tiona sand	35		30	3,230

TABLE OF OIL AND KEY HORIZONS IN APPALACHIAN GEOSYNCLINE[1]
(Continued)

System	Formation	Driller's name		Geologist's name	Approximate thickness, feet	Interval to Pittsburgh coal, feet
Devonian	Chemung	First Balltown sand	36		20	3,350
		Second Balltown sand	37		40	3,430
		Sheffield sand	38		30	3,500
		Chipmonk sand (New York)	39		18	3,550
		First Bradford sand	40	Benson group of West Virginia	40	3,610
		Second Bradford sand	41		20	3,700
		Third Bradford sand	42		15	3,785
	Portage	First Kane sand	43			3,870
		Second Kane sand	44			3,910
		Third Kane sand	45			4,015
		First Elk sand	46			4,350
		Second Elk sand	47			4,395
		Third Elk sand	48			4,450
		Corniferous (McKean County)	49	Onondaga limestone	75	6,555
		Oriskany sand (McKean County)	50	Oriskany sandstone	20	6,630
Silurian		[Salina]		Salina	250	6,980
		Niagara lime (Big Lime)	51	Niagara limestone	130	7,500
		Clinton sand (McKean County)	52	Clinton	240	7,730
		Medina sand (McKean County)	53	Medina sandstone	118	8,130
Ordovician		Trenton lime	54	Trenton limestone		9,230
		St. Peter sand (Ohio)	55	St. Peter sandstone		9,930(?
Cambrian		Potsdam sand (New York)	56	Potsdam sandstone		10,500(?)

[1] Oil horizons are numbered.

of Silurian age and the Oriskany sand of Devonian age may be found to be similarly extensive and uniform when future deep drilling shall have widened the knowledge of their distribution.

Some of these horizons produce only oil and others produce only gas, and a few produce both in the same area. Another fact which should be mentioned is that, although there are many oil horizons in a given area or field, only a limited number of them are productive. This is partly due to porosity conditions within the sand or to its complete absence or to the fact that it lies too deep for profitable exploitation. For example, the Speechley sand lies 2,190 feet below the surface in Clarion County (about halfway between the north and south boundaries of the state) whereas in Greene County, in the southwestern

corner of Pennsylvania, it lies nearly 1,000 feet deeper, while in Barbour County, West Virginia, it lies 1,500 feet deeper. The sands below the Speechley, therefore, lie at comparatively shallow depths north of Clarion County but become increasingly more difficult to reach south of that county. In a general way, therefore, the producing sands of the northern end of the line of fields in Pennsylvania are the sands in the Catskill, Chemung, and Portage formations; whereas, farther south the Mississippian sands and the Pottsville and still higher sands are found to be the producers.

Relation of Production to Structure.—The anticlinal theory which accounts for the relationship of oil and gas with regard to structure had its inception in the Appalachian district. Places can be found where the relationship holds true but they are few and far between. If a study is made of the numerous maps which have been prepared by competent geologists, showing the structure both surface and subsurface and the areas which produce oil and gas,[1] one is forcibly struck with the fact that it is difficult to detect any relationship between the occurrence of oil and the rock structure. Undoubtedly, other conditions than the attitude of the strata must be looked to for a reasonable explanation of the localization of oil and gas. In the Foxburg quadrangle of Pennsylvania, Shaw and Munn find that the great oil pools in the Third and Fourth sands, which furnish by far the greater part of the oil in the quadrangle, signally fail to conform to the structure lines.

Perhaps the most complete discussion of this question is to be found in *Bulletin* 318 of the U. S. Geological Survey publications. In this bulletin, Griswold and Munn state that the Salt and Big Injun sands (p. 16) are pretty thoroughly saturated with water throughout most of the area investigated (Steubenville, Burgettstown, and Claysville quadrangles); that the upper limit of saturation of the Berea sand is about 250 feet below sea level; and that the area of saturation is less in each sand below the Berea. In the Fifth sand, which is the lowest found, the accumulation of oil is nearly at the lowest point in the syncline, because the only areas of ponded water that still remain in it are in the lowest portions of tiny basins along the synclinal trough. In other words, the oil rests upon the water where such

[1] See especially *U. S. Geol. Survey Bulls.*, 279, 286, 300, 318, 454, and 456 and *Folios* 176, 177, and 178.

is present in the sand and occurs in the bottom of the syncline where water is absent.

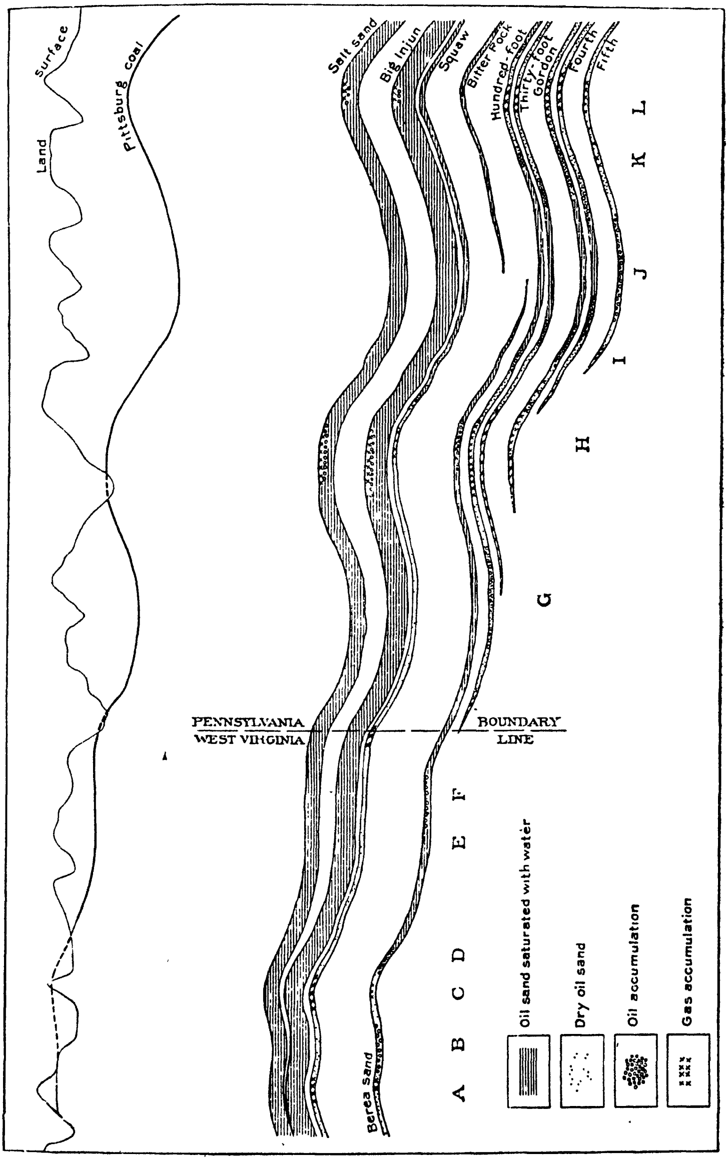

FIG. 10.—Diagrammatic section of sands in central Appalachian region. (*After Griswold and Munn, U. S. Geol. Survey Bull.* 318.)

This explanation, however, is not entirely satisfactory. In the Foxburg quadrangle, for example, the Rattlesnake pool on

the Allegheny River is an example where the oil occurs with salt water almost exactly at the bottom of a shallow syncline, whereas the Rosenberry field not far distant to the northwest lies much higher on the flanks of an anticline. The Hundred-foot sand, which is continuous between the two pools, is not oil bearing in the intervening area. In describing the Carnegie quadrangle,[1] Munn concludes that

> . . . the structural analogy of pools in a given sand relates not so much to definite structural features, as anticlines or synclines, as it does to the height of the pool above some horizontal plane, and that each of the oil- or gas-bearing sands has a series of productive belts at structurally different heights, and that these belts occupy successively lower elevations from northwest to southeast across the Carnegie quadrangle, regardless of the heights or depths of the various folds with which they are associated.

In summary, it may be concluded that structural conditions do exert a controlling influence on the accumulation of oil and gas, but that other conditions very often modify the results so greatly that the relationship between structure and occurrence is obscured. One important modifying condition is the relative saturation of the oil-bearing stratum. If the stratum is only partially saturated with water, the oil may be found on the flanks of a favorable structure instead of near the top; the gas, however, should appear in the crest. If the stratum which carries oil is free from water, the oil may occur as low as the structural conditions will permit, even in the bottom of a syncline. The other, and perhaps more important, modifying condition is differential porosity within a productive stratum. Oil, gas, and water fill pores in the rock and need pores for migration. If the pores become fewer and smaller as the fluids migrate, they will not reach the destination toward which the controlling forces are urging them. If the pore spaces cease to exist in the direction of migration, then migration also ceases. Finally, it must also be remembered that oil and gas reservoirs are variable in thickness and may even pinch out altogether.

NEW YORK

The distribution of oil and gas in the state of New York is limited to the western half of the state and to only a small part

[1] *U. S. Geol. Survey Bull.* 456.

of that. The fields of importance are located in southern Allegany and southern Cattaraugus counties nearly in the southwestern corner of the state. In this restricted area, both oil and gas are found. Outside the area, small patches of gas have been found at somewhat widely scattered localities. Chief among these are Ontario, Oswego, Steuben, and Schuyler counties. Prospecting has been carried on over a wide belt and some deep wells were drilled in nearly every county which seemed to have possibilities. The unsatisfactory results obtained in these tests indicate that large pools or major extensions of known pools are not to be expected.

The finding of the first oil seepage near Cuba, in Allegany County, was mentioned in the preceding pages. Other seepages, especially of gas, were found later. Ashburner[1] lists a great many of them which he took from Dr. Beck's report. Among the counties in which seepages are known, he lists, Dutchess and Columbia counties in the extreme eastern part of the state, besides practically every county in the western part of the state. Ontario County is credited with having an abundance of them, the most noted of which is in the town of Bristol. The earliest published reference to natural gas in the state was to the gas springs near the village of Fredonia, on Canadaway Creek, in Chautauqua County, about three miles south of the lake shore. It appears that gas was first utilized here in 1821, being the first use made of it in the United States. In 1824, when Lafayette passed through the village, it was being so used in the hostelry which occupied the site of the present Taylor House.

Tectonic Conditions.—The tectonic conditions of the oil and gas fields of New York may be inferred from a glance at Fig. 9, which shows, by means of contours on the Pittsburgh Coal horizon, the spoon-shaped outline of the Appalachian trough. New York lies at the northern end where the strike of the rocks is more nearly east and west and where the dip into the trough is southwest, south, and southeast. The normal monoclinal dip is interrupted by small noses, ravines, domes, and terraces. Ashburner reports that some of these small structures have remarkably steep dips for short distances.

Stratigraphy.—The succession of rocks in west-central and western New York includes all systems of the Paleozoic group

[1] Ashburner, Charles A., Petroleum and natural gas in New York State., *Trans.* A.I.M.E., Duluth Meeting, July, 1887.

except the Permian. These rocks were studied in great detail by many workers among whom Hall, Vanuxem, Emmons, Williams, and Prosser stand out prominently. A very good summary of the stratigraphic conditions is given by Prosser in the *Bulletin* of the Geological Society of America for 1893. His chart, showing the thickness of the New York Paleozoic rocks for different sections of the state is given below. It will be noted that the Devonian rocks down to the black (Genesee) shale are approximately 2,500 feet thick. It is in this part of the section that most of the productive horizons of the Appalachian field are found. Also, the Lower Helderberg and Onondaga Salt group together constitute a considerable portion of the total section, which is not true farther south. The Potsdam and the Calciferous sandstones are listed and it is found that they are within drilling depth. These horizons are usually too deep for profitable oil exploration in the rest of the Appalachian region. On the western edge of the region in central and southern

CHART SHOWING THICKNESS OF NEW YORK PALEOZOIC ROCKS

System	Formations	Western, feet	West-central, feet	Central, feet	Eastern, feet	Depth, feet
Devonian	Catskill				3,900	
	Olean to Wolf Creek	300				
	Chemung shale and sandstone	1,500(?)	1,200	2,250	1,130	2,000
	Portage shale and sandstone	900	1,780		1,315	
	Genesee black shale	100	100	20	1,075	2,020
	Tully limestone	0	30	25		2,045
	Hamilton shale	750	1,142	1,785		3,145
	Marcellus shale	50	82	100(?)	900	3,245
	Onondaga limestone	150	78	10	851	3,315
	Corniferous limestone			60	40	
	Oriskany sandstone	0	13	20	10	3,335
Silurian	Lower Helderberg limestone	0	115	120	200	3,455
	Onondaga Salt group	600	1,418	1,239	0	4,155
	Niagara limestone	180	335(?)	52	0	4,205
	Clinton	80	83	323	0	4,405
	Medina sandstone	1,075	942	520	0	4,805
	Oswego sandstone	83	210	107	0	4,905
Ordovician	Lorraine shale	598	820	640	3,500	5,505
	Utica black shale			233	.....	5,685
	Trenton limestone	954	842	637+	500	6,015
	Calciferous	137	150(?)	320(?)	.....	6,365
Cambrian	Potsdam sandstone	40(?)	....	410(?)	.....	6,775
	Archean basal complex					

Ohio, they are encountered in many deep wells and are usually referred to as the Magnesian lime. The top zone has been differentiated as the St. Peter by some geologists working in that part of the region.

Producing Horizons.—Sandstones as well as limestones produce oil and gas in New York. Nevertheless, the number of important zones is decidedly limited and does not compare to those of Pennsylvania. The largest quantity of gas comes from the Medina sand of the Silurian system, which is an unusually persistent producer. In Oswego, Ontario, Yates and Onondaga counties, small amounts of gas are secured from the Trenton limestone. Sands of the Portage and lower Chemung formations produce gas in Cattaraugus and Allegany counties. A certain amount of gas has also been found in the Potsdam sandstone which thus takes rank as the oldest producing horizon in the United States.

The oil horizon of Allegany County, which is locally known as the Richburgh, is probably the same horizon as the Third Bradford sand. This sand lies 1,729 feet below the Olean conglomerate in this region which compares with an interval of 1,779 feet 26 miles farther south in the Bradford district.

Character of Oil and Production Statistics.—Most of the oil produced in New York is dark green in color, ranges in specific gravity from 38 to 47° and has a paraffin base. Since 1864, when the first well was drilled in Cattaraugus County, over 14,000 wells have been drilled and the present fields comprise 50,000 acres. The wells are remarkably long lived, as indicated by the fact that over half of those now producing are 20 years old, or more, many of them are over 30 years old, and a few have produced for 40 years. The peak of production was reached in the early 'eighties when 5,000,000 barrels annually were obtained. It declined slowly in subsequent years, but the total up to date makes the impressive showing of over 70,000,000 of barrels. A revival has recently been started by means of flooding the sands.

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PENNSYLVANIA

The oil and gas fields of Pennsylvania are located in the western part of the state where they extend in a zone trending northeast and southwest. This zone is approximately 75 miles wide and 225 miles long. Figure 11 shows the location of this area and also shows that the oil pools lie more westerly than the gas pools, in a general way. The counties in which production has been found are Potter, McKean, and Warren, along the northern border of the state. Then toward the south it is found in Elk, Forest, Venango, Jefferson, Clarion, Mercer, Armstrong, Butler, Lawrence, Beaver, Allegheny, Westmoreland, Washington, and Greene counties.

Oil springs were known for a long time before the first well was put down in 1859. There were seepages along Oil Creek in Venango County as well as at many other points. It was probably because of these seepages that Colonel Drake decided to place his first well in the valley of the Oil Creek below Titusville. Many a later oil field has been discovered by following similar methods. Nevertheless, there was an element of good fortune in it, for, without the mechanical refinements in well-drilling equipment now enjoyed, he succeeded in obtaining oil at the shallow depth of 69 feet.

Tectonics.—The regional structural conditions of the oil fields of Pennsylvania have been set forth in a general way in the introductory part of this chapter. Figure 11 indicates that the fields lie on the west flank and along the axis of the Appalachian trough. This trough pitches toward the southwest, the axis passing nearly through the southwest corner of the state. If the fields of southeastern Ohio as well as those of Pennsylvania are considered, it is noted that oil occurs quite a bit higher on the west flank of the geosyncline than on the

east side. Indeed, it occurs about 500 feet higher on the west flank. The reason for this will be given later.

Stratigraphy.—In the oil fields of western Pennsylvania, there is a complete succession of the systems of the Paleozoic era from

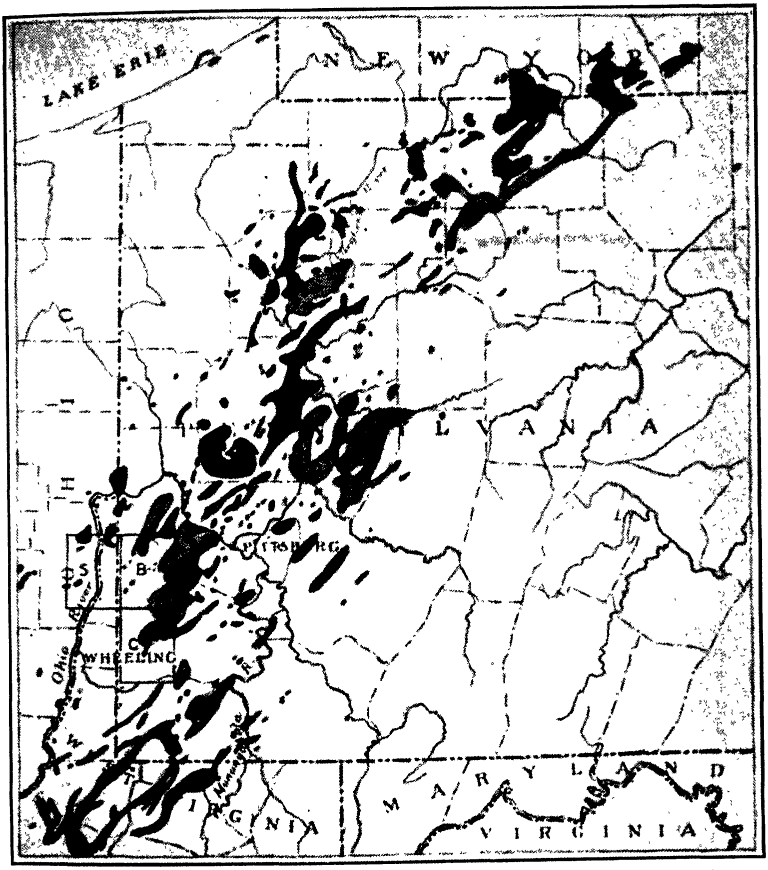


Fig. 11.—Map of the oil and gas fields in western Pennsylvania and adjacent regions. (*After U. S. Geol. Survey.*) Gas fields indicated by light stippling and oil fields by dark stippling.

the Cambrian to the Permian. Not all the systems are accessible, because of the great thickness of some of the systems. The Permian system has a thickness of 1,100 feet, a full section of which can be seen only in the southwestern corner of the state. The Pennsylvanian is 1,500 feet thick. The Devonian is by far the thickest system. The shales alone, from the

Catskill to the Marcellus, inclusive, total 4,000 feet and the limestones below the shales add another 300 feet. The Silurian is 1,500 and the Ordovician perhaps 1,800 feet thick. The last system has not been reached by the drill so far as the writer is aware, and the thickness is taken from adjacent areas.

In this connection, it may be profitable to study the results of deep-well drilling in Pennsylvania and surrounding states. The following table is taken from an article by Robinson[1] in which he has brought together 32 wells on a comparative basis. For our purposes, 18 of these will suffice and they are given in the table on the next page, arranged according to their position in the geosyncline, those highest being listed first. Some interesting convergence data are brought out by the table. For instance, the interval between the Berea and the Corniferous limestone varies from 5,366 feet in Elk County, to 5,845 in Indiana County to 6,420 in Westmoreland County to 6,018 in Marion County, West Virginia, to 2,942 in Kanawha County. (These points are very nearly in a north to south line.) These figures indicate that the region of most rapid subsidence during upper Devonian time lay on the site of Westmoreland County. The very remarkable convergence between Marion and Kanawha counties, of about 3,000 feet (in about 90 miles) does not seem reasonable. However, if well No. 17 is taken into consideration, in which the Oriskany is placed at 3,675, ample support is found for the other figures. The thickness of the Corniferous is 90 feet in well No. 16. Assuming the thickness to be approximately the same in well No. 17, then the interval between the Berea and the Corniferous would be 1,462 in well No.17. This well is located west of No. 16 in Cabell County, a scant 40 miles in distance. If the horizons have been identified correctly, there is a convergence between the Berea and the Corniferous of 1,390 feet from Kanawha to Cabell counties. All this indicates that the Devonian shales, which appear to be very largely the original source of the Appalachian oils, become rapidly thinner from the northern boundary of West Virginia toward Kentucky. In the discussion of the oil fields in Kentucky, there will be occasion to take up this matter further (see Fig. 9, p. 29).

One more interesting convergence must be pointed out. In well No. 14, the Berea is found at 1,610 and the Corniferous at

[1] Robinson, J. French, Deep-well drilling in eastern field, *Oil Gas Jour.*, p. 157, May 17, 1928.

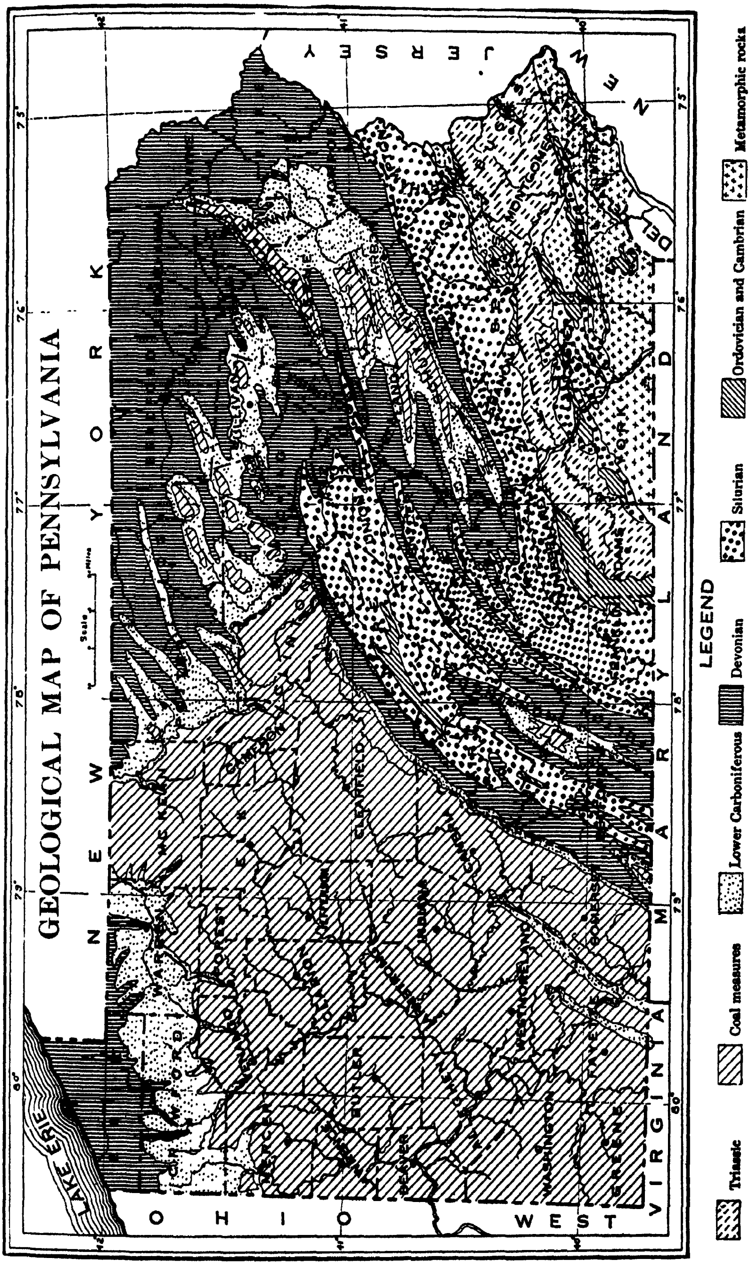


FIG. 12.—Geologic map of Pennsylvania. (*After Top. & Geol. Survey of Penna.*)

SUMMARY OF DEEP-WELL OPERATIONS IN THE APPALACHIAN OIL FIELDS

Number	Berea	Bradford or Benson	Corniferous	Oriskany	Clinton	Medina gray	Total	Remarks
1	.....	.....	.....	.....	2,260	2,470	3,572	Gas
2	.....	1,120	4,065	4,135	5,320	5,642	5,760	Dry
3	.....	.....	2,852	3,025	.....	.....	3,633(?)	Dry
4	300	.....	.....	.....	3,601	.....	3,789	
5	442	.....	.....	.....	2,075	.....	2,088	
6	1,010	.....	.....	.....	3,709	.....	3,805	
7	.....	.....	3,825	3,980	.....	.....	4,250	Dry
8	.....	1,456	.....	4,312	.....	.....	4,900	Dry
9	1,512	4,166	7,363	.....	.....	.....	7,386	Dry
10	1,000	3,420	6,955	7,018	.....	.....	7,579	Dry
11	388	2,470	6,786	6,807	.....	.. ..	7,756	Gas
12	1,015	.....	.....	6,860	.....	.....	7,003	Dry
13	110	2,108	5,308	5,476	.....	.....	....	Drilling
14	1,610	4,100	6,008	6,045	... .	... .	7,248	Dry
15	905	.....	.....	4,499	.....	. ...	4,597	Oil
16	2,093	.....	4,945	5,035	.....	.. ..	5,595	Dry
17	2,123	.....	.....	3,675	4,500	.....	4,750	
18	.....	.....	.....	2,750	.....	. ...	2,770	Dry

1. City of Erie, Erie Co., Pa.; 2. United Natural Gas Co., McKean Co., Pa.; 3. United Natural Gas Co., Crawford Co., Pa.; 4. United Natural Gas Co., Akron, Summit Co., Ohio; 5. Federal, Fuel and Gas, Lancaster, Ohio; 6. Zanesv. Oil and Gas, Muskingum Co., Ohio; 7. Parsons Pulp, Tucker Co., W. Va.; 8. Hope Natural Gas Co., Preston Co., W. Va.; 9. Hope Natural Gas, Harrison Co., W. Va.; 10. Hope Natural Gas, Marion Co., W. Va.; 11. People's Natural Gas Co., McCance, Westmoreland Co., Pa.; 12. Phillips Gas, Indiana Co., Pa.; 13. United Natural Gas Co., Elk Co., Pa.; 14. People's Natural Gas Co., McDonald, Washington Co., Pa.; 15. Hope Natural Gas Co., Wood Co., W. Va.; 16. Edwards Oil Co., Kanawha Co., W. Va.; 17. Nixon Oil Co., Cabell Co., W. Va.; 18. Cabell Co., W. Va.

6,008 feet, making an interval of 4,398 feet between the two key horizons. This well is located in northwest Washington County, Pennsylvania. In well No. 11, the Berea is found at 388 and the Corniferous at 6,786 feet, making an interval of 6,398 feet. These wells are about 80 miles apart in an east to west direction and show a convergence of 2,000 feet. This does not seem out of keeping with the observations made by geologists in Ohio, as it amounts to an average of only 25 feet per mile. For reference, and to furnish a complete picture of the succession of rocks in the oil fields of Pennsylvania, a generalized section of the Paleozoic rocks in western Pennsylvania is given here.

GENERALIZED SECTION OF PALEOZOIC ROCKS IN WESTERN PENNSYLVANIA

System	Formation	Thickness, feet	Character
Permian	Greene	700	Alternating beds of shale, sandstone, limestone and coal. Found only in southwest Pennsylvania
Permian	Washington	350	Shale, limestone, sandstone, and coal. The Waynesburg sandstone is the most persistent member and the upper Washington limestone at the top is next in importance
Pennsylvanian	Monongahela	200 to 400	At northeast end of outcrop in Greene County, etc., limestones make up nearly one-half of formation with six distinct coal beds. Southward limestones disappear and all coals except *Pittsburgh* which is basal member. Also sandstone and shale
Pennsylvanian	Conemaugh	500 to 700	Lower part sandy, middle and upper part mostly red and green shales, a number of thin limestones and six to ten thin coals. Ames limestone is important key horizon. Saltsburg sandstone often correlated with First Cow Run sand. Non-conformity at top
Pennsylvanian	Allegheny	300	Shale, sandstone, and coal. Yields about 40 per cent of bituminous coal mined in Pennsylvania. Delimited above by massive Mahoning sandstone and below by massive Homewood sandstone
Pennsylvanian	Pottsville	200	Consists of three members: Homewood sandstone at top, Mercer coal group, and Conoquenessing sandstone. This formation thickens enormously to south being over 5,000 feet thick in West Virginia and eastern Kentucky. Important unconformity at base
Mississippian	Mauch Chunk	50 to 2,000	Red and green shale and greenish sandstones. Varies greatly in thickness because of *unconformity* at top. A line representing the north and west edge runs west from a few miles south of Pittsburgh to Ohio-Pennsylvania line and from same locality northeast through Saltsburg and Indiana
Mississippian	Greenbrier	50	Limestone. Varies considerably in thickness
Mississippian	Pocono	950	Sandstones, shales, and thin limestones. The upper member is called Burgoon and is "Big Injun sand." Probably equivalent to Logan and Black Hand of Ohio. Important non-conformity at base. Middle portion is called by Butts Cuyahoga and lowest member Berea
Devonian	Catskill	600	Catskill on Allegheny front mostly red shale and sandstone, 2,000 feet thick. Changes gradually toward west to greenish shales and thin sandstones 500 to 600 feet thick. Western phase called, by Butts, "Conewango." Overlying Knapp formation included in Catskill
Devonian	Chemung	1,100	Shale and sandstone, large amount of purplish rock in upper half (pink rock of drillers). Includes Speechley, Tiona, Bayard, Elizabeth and Bradford sands
Devonian	Portage	1,000	Gray, sandy shale, and thin sandstones. Contains the Kane and Elk sands
Devonian	Genesee	75	Black shale on outcrop in Allegheny front. Not definitely recognized in well logs
Devonian	Hamilton	1,000	Dark, greenish, hackly shale above darker fissile shale containing sandstones at Altoona. In Starbrick well,[1] dark to chocolate, soft, clay shale which is highly calcareous for 200 feet above base. In the midst of calcareous zone is bed of limestone 32 feet thick which might be mistaken for Onondaga
Devonian	Marcellus	200	Black fissile shale. 200 feet thick in Starbrick well
Devonian	Corniferous	80	Light-grey limestone, contains in places a considerable amount of chert (hence Corniferous). This limestone is missing at Altoona and along Allegheny front. Upper Helderberg limestone of some authors. Includes Onondaga limestone of New York
Devonian	Oriskany	20	Thick-bedded, coarse-grained, grey or buff sandstone. 177 feet thick at Altoona (Butts)
Silurian	Salina	250	Shales and thin limestones. Salina, Niagara and Clinton are 1,800 feet thick on Allegheny front[2]
Silurian	Niagara	130	Limestone. Big Lime of Ohio
Silurian	Clinton	300(?)	Shales and limestone
Silurian	Medina	100(?)	White sandstone, 425 feet on Allegheny front
Ordovician	Cincinnati	500(?)	Shales. Hudson and Utica shales 1,850 feet on Allegheny front
Ordovician	Trenton	700(?)	Limestone

[1] Well, deep well near Warren, Pa.

[2] [illegible] Pa., p. 203, 1906–1908.

Oil Horizons.—At least 30 different horizons in the stratgraphic section in western Pennsylvania produce oil or gas, or both. It is difficult to say which are the most important, as this would imply the compilation of data regarding each pool in the state. This has not been done so far as the author is aware and probably would be impossible, as many wells are now abandoned and only imperfect records have been kept of production from different sands in many places. According to a list of producing fields compiled by Munn,[1] the following are important gas-producing sands: Bradford, Speechley, Murrysville (Berea) and Hundred-foot. The first named produces at the northern end of the petroliferous area. The Berea is important as far south as the Indiana and Elder's Ridge quadrangles. The Hundred-foot produces in the Clarion quadrangle and as far south as the Sewickley quadrangle. It splits south of that point into several sands one of which, the Fifty-foot, is an important producer as far south as the corner of the state. The Big Injun accounts for production over a wide area also. It becomes prominent in the Claysville quadrangle and continues so as far as the southwest corner of Pennsylvania. Among the sands which produce oil, the Hundred-foot seems to lead in the area covered, followed by the Gordon, Fourth, and Fifth sands. Toward the southern end of the oil-producing territory, the higher sands begin to produce, among which the Big Injun stands out, followed by the Dunkard. Sands which seem to produce only in limited areas are the following: Salt, Maxton, Big Lime, Squaw, Snee, Bayard, Elizabeth, Tiona, Sheffield, Kane, and Elk (See page 32).

The deepest producing horizons at present are the sands in the Portage formation—the Kane and Elk. These are not important. The deepest important sands are the Bradford sands near the base of the Chemung. Deeper sands than the above have been found, but up to date none of them has proved of commercial value. The most looked for is probably the Clinton sand, which is so valuable in central Ohio. The white Medina, which is important in western New York, has been reached in a few wells (see list of deep wells on a previous page). The Corniferous, which is a very prolific producer in Kentucky, has been found in a few wells also, but none of these have found production in Pennsylvania. The Trenton limestone, which

[1] *Report Top. Geol. Survey Comm.*, p. 298, 1906–1908.

produces oil in western Ohio, lies at very great depths and has not been reached by any well in this part of the Appalachian area. The Oriskany has been reached by about 14 wells in Pennsylvania or closely adjacent areas. It produces oil in one well and gas in another.

Relation of Oil to Structure.—A great deal has been written about the relation of oil to structural features in the Pennsylvanian fields. In the early days, when White traveled through the fields,

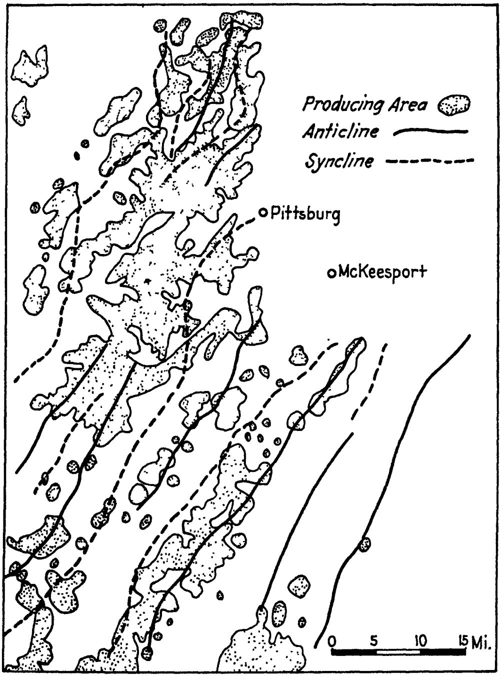
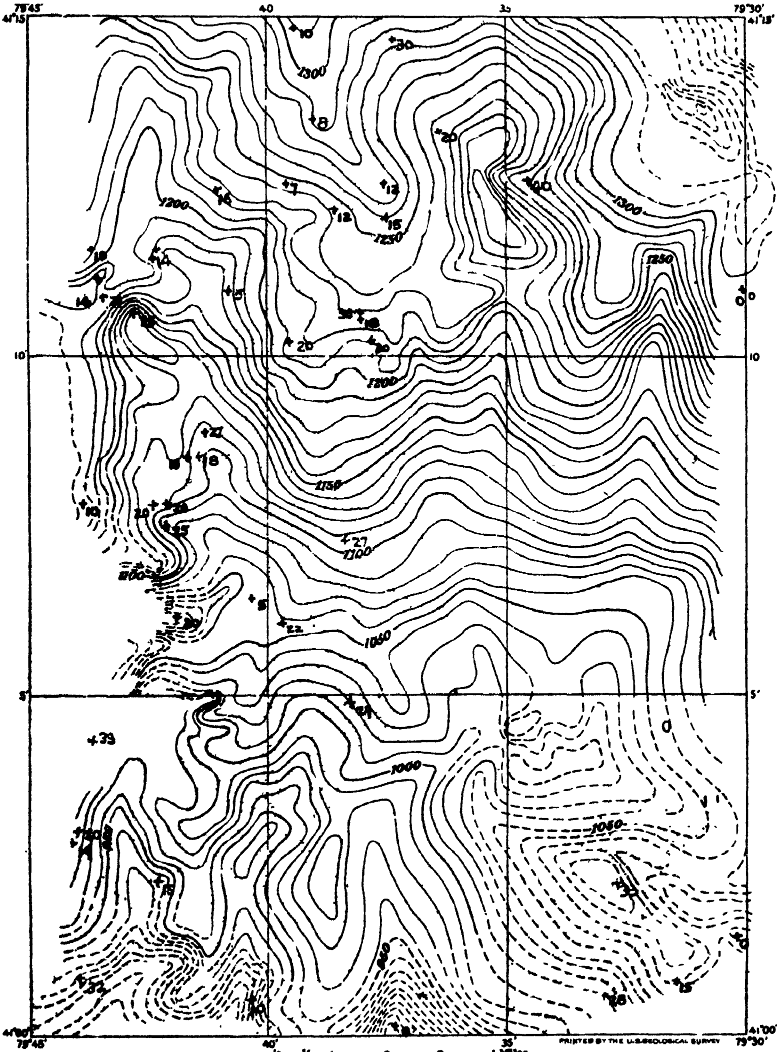


FIG. 13.—Sketch map of part of southwestern Pennsylvania showing relation of structure to production. (*After U. S. Geol. Survey Bull.* 456.)

the relationship to anticlines appeared fairly convincing. Later on, when Shaw and Munn and Griswold began to examine critically the validity of the anticlinal theory, many doubts arose as to its correctness. So many anomalous conditions were noted (see Fig. 13), that the theory had to be modified to explain accumulations on the flanks of an anticline and even in the synclines. It was suggested that the water level in the sand exercised the controlling influence, that the oil was to be sought just above the water level after that was determined for each



SKETCH MAP SHOWING THICKNESS, EXTENT, AND STRUCTURE OF THE THIRD OR GORDON SAND IN THE FOXBURG QUADRANGLE, PENNSYLVANIA

Numbers show thickness of sand in feet at points indicated by crosses.

Structure contours on top of Third or Gordon sand
Contour interval 10 feet; datum plane 1000 feet below sea level.

Fig. 14.—Sketch map showing the thickness, extent and structure of the Third or Gordon sand in the Foxburg quadrangle, Pennsylvania. (*After Shaw and Munn, U. S. Geol. Survey Bull.* 454.)

sand. Where the water was absent, the oil might appear in the bottom of the syncline. So far, it has not been possible either to prove or disprove the latter assumptions. In recent years, the tendency has been to give greater weight to other factors besides the structural attitude of the oil-bearing horizon. Such modifications as differential porosity induced by cementation or fineness of grain, complete pinching out of the sand (see Fig. 14), and similar conditions probably have more to do with the precise location of an oil pool than its relative position with reference to the axis of a fold. The most careful study of the structure of a portion of the Appalachian fields that has been carried out is probably the work of Griswold and Munn, in the Steubenville, Burgettstown, and Claysville quadrangles.[1] Careful measurements were made to determine the surface structure. Well logs were plotted according to elevation and position to determine convergence. Then convergence sheets were made and finally the subsurface structure on important oil horizons was derived from these two preliminary maps. The complete set of maps accompanies the bulletin and much profit may be derived from their study.

The McDonald Oil Field.—The greatest field in the area under discussion, and one of the greatest in the whole Appalachian geosyncline, is the McDonald field. The first wells were drilled in the spring of 1891 and within 6 months the field was producing 75,000 barrels per day. This may not seem so remarkable when compared with the Seminole field with its air lift, but it compares favorably with other pools elsewhere. The largest well produced 18,000 barrels per day of high-gravity oil, which comes near the record. Many wells started off at 2,500 barrels per day. This field crosses the boundary line between Washington and Allegheny counties and lies in the eastern part of the Burgettstown and western part of the Carnegie quadrangles.

The most prominent surface structures are the Cross Creek syncline and the Candor dome. The Cross Creek syncline runs east and west along the south side of the field connecting the major synclines called West Middletown syncline running through Burgettstown and the Nineveh syncline which runs through Carnegie. The Candor dome lies about four miles northwest of the field. On the subsurface map, these features are reflected fairly well, somewhat more faithfully perhaps by

[1] *U. S. Geol. Survey Bull.* 318.

the contours on the Hundred-foot than by those drawn on the Gordon sand.

Oil is found in this field in seven different sands. Of these, the Fifth is by far the most important followed next in order by the Gordon. The other sands which produce oil are the Fourth, Gordon Stray, Thirty-foot, Gantz, and Fifty-foot sands. The controlling factor which seems to account for the large amount of oil in the Fifth sand is the fact that it pinches out up the dip. Little or no water shows in the sand below the oil. This is not true of the other sands, however, and the fact that the pools are located about midway between the axis of the syncline and the higher structure to the northwest is explained by Munn as due to the small amount of water in the sands. The Hundred-foot sand is the only one that carries much water.

One of the remarkable features in connection with the McDonald pool is the thinness of the sands in comparison to the amount of oil produced. The thickness of the sands in some of the largest wells is given as 28 to 30 feet. One well had produced over 2,000,000 barrels up to 1908 and was still producing at the rate of 15 barrels per day after 16 years of flow. The oil-bearing area of the Fifth sand has a length of about 11 miles and a maximum width of about 3 miles. The thickness of the Fifth sand averages 20 feet, but in places runs as low as 6 and as high as 40 feet. The oil comes from a coarse pebbly "pay streak" in the sand which averages about 6 feet in thickness. Where this pay streak is absent, the sand is barren.

Production Statistics.—From 1859 to 1875, Pennsylvania produced practically all the oil in the United States. Also, in that year, the state produced 88 per cent of the oil produced in the world. In 1881, the total production of the United States was 27,700,000 barrels of which 26,800,000 barrels is to be credited to Pennsylvania. In 1891, the state reached its maximum production when 31,400,000 barrels were produced. Since then, the production has dropped off gradually until in 1929 it amounted to 12,000,000 barrels. In the production of natural gas the peak was reached in 1909 when 166,000,000,000 cubic feet were produced.

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WEST VIRGINIA

The oil fields of West Virginia, as did oil fields of Pennsylvania, started at a point where natural gas exuded from the ground. This was at Burning Springs in Wirt County. An old brine well at this place was reopened when the excitement started by Colonel Drake at Titusville penetrated to this part of the country. This well yielded nearly 50 barrels a day. A year later, the Llewellyn well was drilled to a depth of 100 feet with the crude tools then in use and, fortunately again, it was located on the most pronounced anticline in the whole Appalachian region—the Volcano anticline where the producing horizons could be reached at shallow depth. It had a remarkable production of nearly 2,000 barrels per day and was quite a sensation for a time, so that many other wells were started in the vicinity. These wells were destroyed by Confederate raiders in 1863. Two years later, drilling was started again and with pronounced

success along a line running northward on the anticline toward Eureka in Pleasants County.

On account of the fact that the producing horizons lie deeper toward the east, drilling in that part of West Virginia was not successful, so that it was not until 1888, when the machinery for deep drilling had been perfected, that new districts were opened up. From then on to 1900, progress was rapid indeed and many

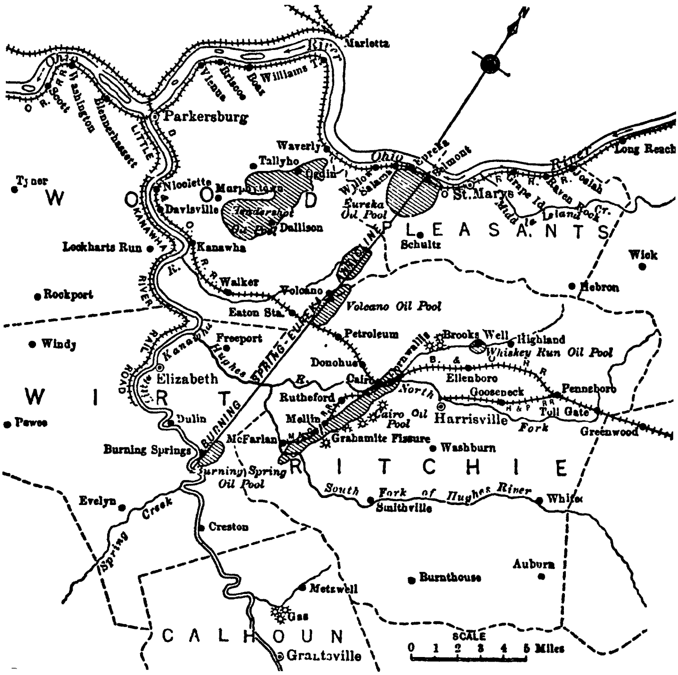

FIG. 15.—Map showing the location of the Burning Springs-Volcano anticline. (*After White, Bull.* Geol. Soc. Am., **10.**)

of the pools in Ritchie, Doddridge, Marion, and Hancock counties were discovered.

Tectonics.—The oil fields of West Virginia lie in the Appalachian geosyncline which has its deepest basin in Wetzel County in the northwestern part of the state. This is based on the information furnished by the attitude of the Pittsburgh coal. The contours on the Big Injun sand show the deepest part of the structure in nearly the same place. If the attitude of the Corniferous limestone is taken as a guide, however, the deepest

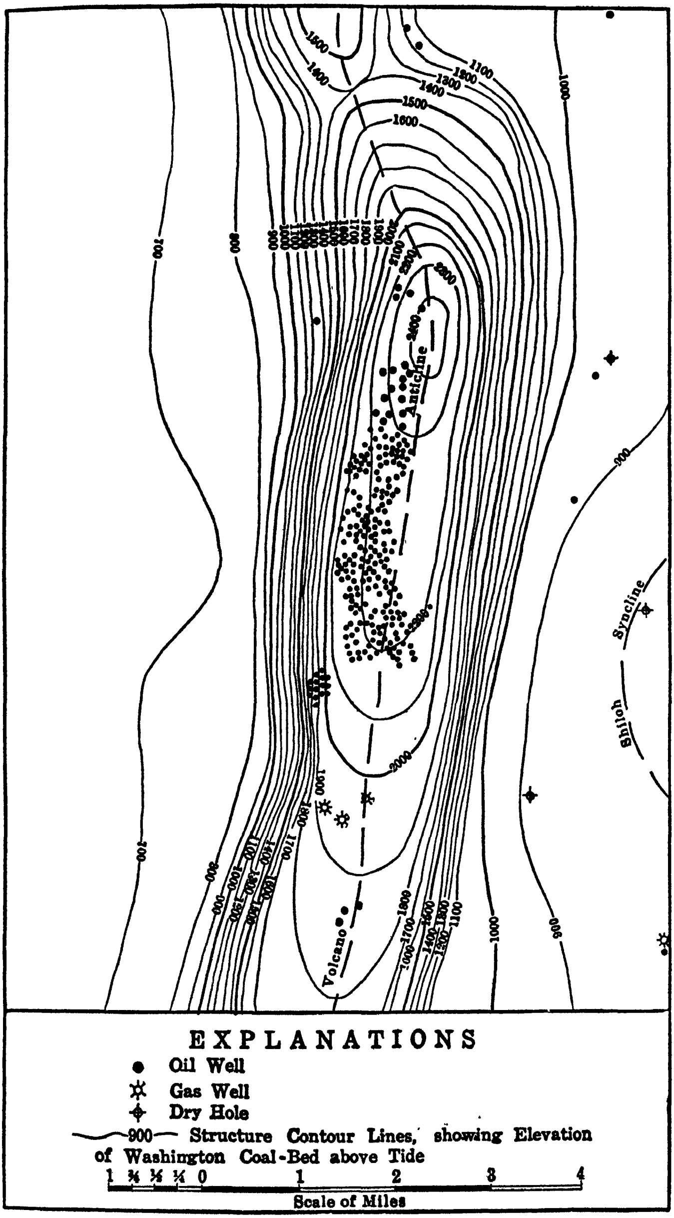

FIG. 16.—Geological structure of a portion of the Volcano anticline in West Virginia. (*After White and others, Bull.* Geol. Soc. Am., **28**, 564.)

part would probably appear some 50 miles farther north in Westmoreland County, Pennsylvania. An outstanding tectonic element which reverses the normal influence of the geosyncline is the Burning Springs-Volcano anticline (see Fig. 16). This anticline trends nearly north from Wirt County through Wood and Pleasants counties across the Ohio River into Ohio. The area in which the contours close is about 2 miles wide and the

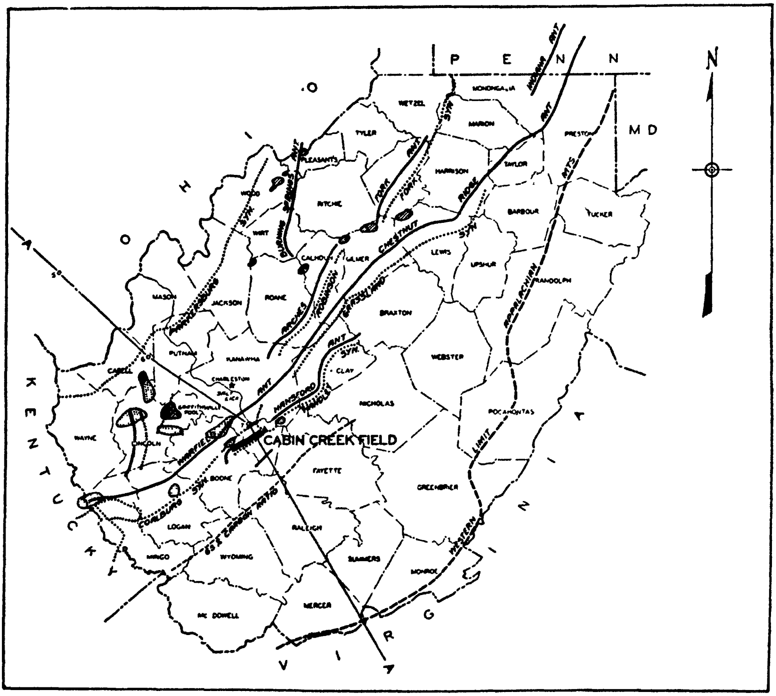

Fig. 17.—Map of West Virginia showing structural axes, Berea oil and gas pools and structural position of the Cabin Creek field. (*After Wasson, Bull. A.A.P.G.*, **11**, 706.)

reverse dip is as much as 900 feet. The dip on the flanks of the anticline measures 700 feet to the mile at one place.

Other important structural elements are the Parkersburg syncline which starts in central Wood County and trends southwest through Jackson, western Putnam, and central Cabell counties where it turns west to enter Kentucky. Running south through Doddridge, Calhoun, and Roan counties into Kanawha County is the Arches Fork anticline and associated Robinson Fork syncline (see Fig. 17). The longest continuous

anticline is the Warfield-Chestnut Ridge anticline which trends northeast and southwest nearly through the center of the state. Closely associated with it are the Grassland syncline in the north and the Coalburg syncline farther south. Still farther east and trending nearly parallel to the others is the Hansford anticline with its companion the Handley syncline. This structure lies close to the 65 per cent carbon-ratio line and therefore is the last to be of interest to the petroleum geologist.

Detailed structure maps of the oil fields of the state show a multiplicity of smaller structural modifications of the major elements. There are the usual terraces and many small domes as well as noses, basins, and ravines.

Stratigraphy.—The record of rock succession in western West Virginia where the oil fields are located is very similar to that of western Pennsylvania. Deep wells in Cabell and Kanawha counties have penetrated to the Clinton horizon in the Silurian and slightly beyond. On the surface, Permian rocks are exposed. From the careful studies made in the folded Appalachian Mountains which extend through the eastern tier of counties of the state, information is obtained regarding the Ordovician and Cambrian rocks which probably underlie the oil fields.

Reger has brought together this information in a table and columnar section which are reproduced in Fig. 18. It will be seen that there are many points of similarity with the section described above for the adjoining state. Some of the thicknesses given in the lower part of the section, for which information was meager at the time the table was compiled, may be more precisely stated now as a result of deep wells drilled in various counties. The Oriskany sandstone seems to have a thickness of only 10 feet in Cabell and Kanawha counties, but it becomes thicker toward the deeper part of the basin for in Marion County it is 20 feet thick and farther east, in Tucker County, 80 feet thick. The Clinton sand seems to have been penetrated in only one well—that of the Nixon Oil and Gas Company, in Cabell County. In the record of this well, it has a thickness of 40 feet. The shales below the Clinton in this well seem to be over 200 feet thick. The thickness of the limestones between the Oriskany and the Clinton is 825 feet. The thickness of the Corniferous (Onondaga) is 90 feet in Kanawha, 20 feet in Harrison, 63 feet in Marion, and 20 feet in Tucker counties.

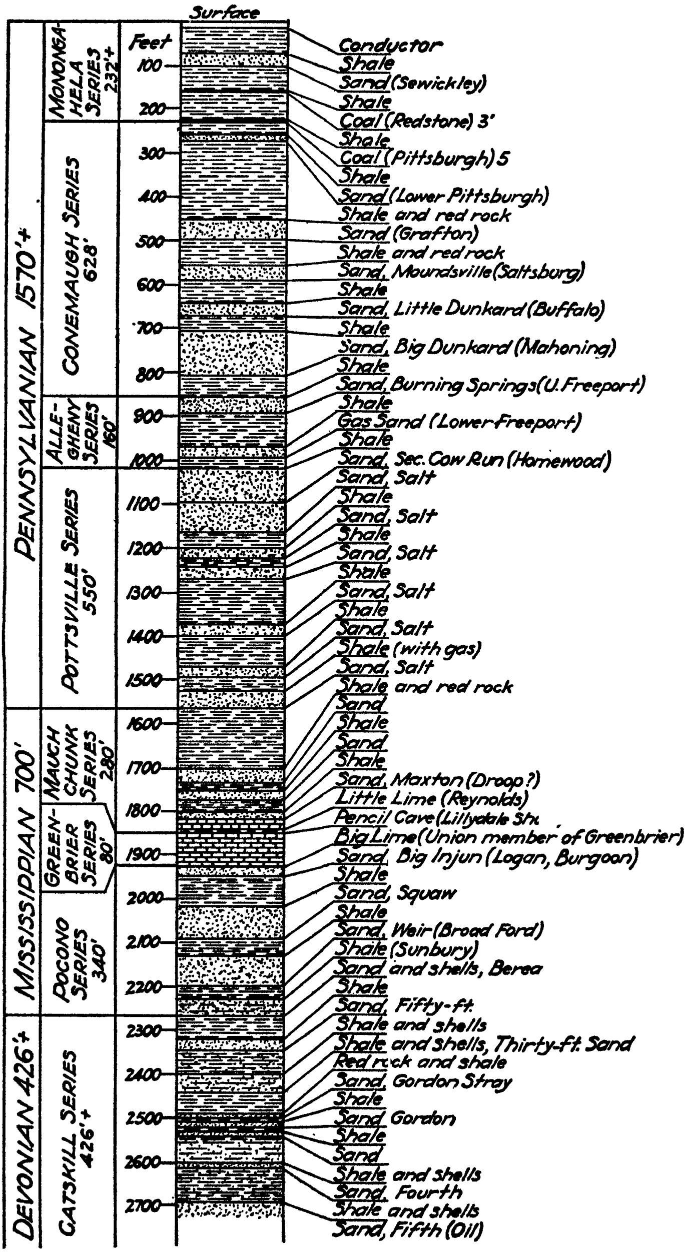

FIG. 18.—Typical well record in Lewis and Gilmer counties, West Virginia, showing position of producing horizons. (*After Reger, Bull.* A.A.P.G., **11**, 581.)

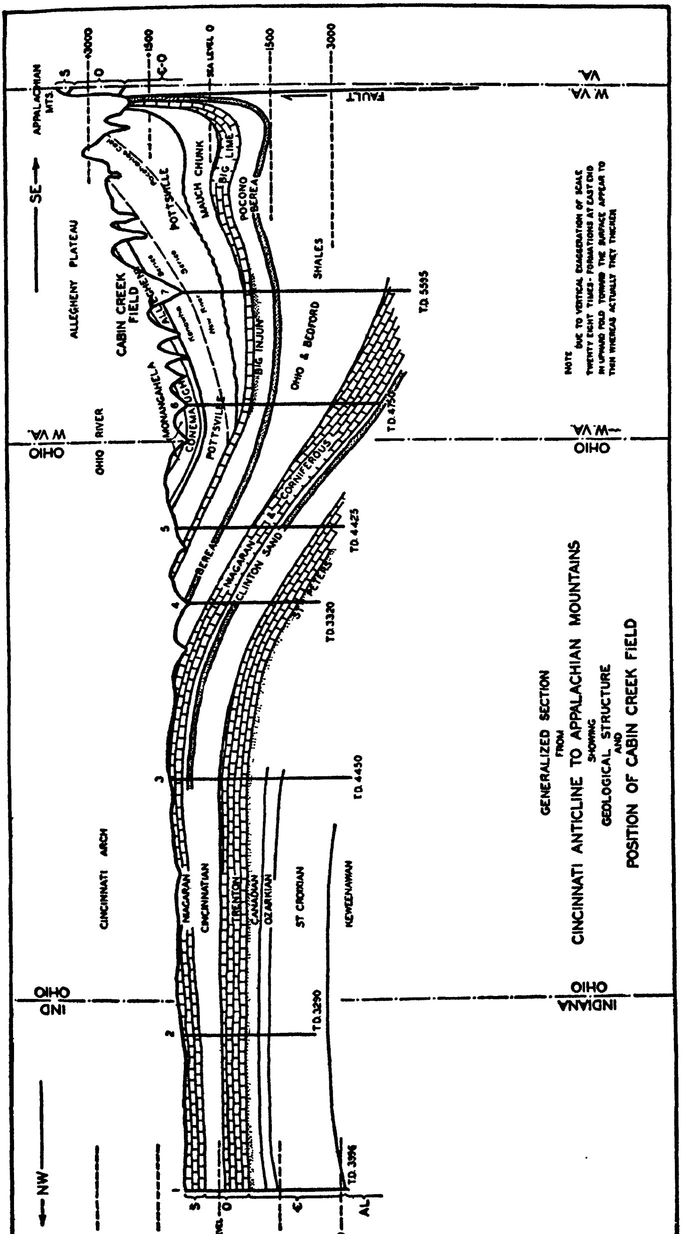

FIG. 19.—Generalized section from the Cincinnati anticline to the Appalachian Mountains showing geoloic structure and position of Cabin Creek field. (*After Wasson, Bull.* A.A.P.G., **11**, 710.)

The convergence of the Devonian shales from east to west is brought out by wells drilled in Cabell and Kanawha counties. In the distance of 40 miles between the two localities, the shales change in thickness from 2,852 feet to 1,552 feet—a difference of 1,300 feet. Between Marion County on the north and Kanawha County on the south, the change is more remarkable, amounting to 3,000 feet in about 90 miles, or at the rate of 33 feet per mile. It thus appears that the convergence along the axis of the geosyncline is about the same in this part of that great structural element as the convergence from the side toward the center. Figure 19 illustrates this convergence in a striking manner.

Oil Horizons.—The great number of zones in the stratigraphic section which yield oil or gas in Pennsylvania is considerably diminished in West Virginia. The sands of the Portage and Chemung formations are entirely wanting and the lowest productive horizon is the Bayard sand near the base of the Catskill formation. In the Panhandle of West Virginia, the most important horizon is the Berea at the base of the Mississippian system. Above this the Salt sand and the Big Injun sand are of some consequence and below this the Hundred-foot is a good producer, as is the Gordon. The Thirty-foot sand lying about 100 feet below the Hundred-foot is of some importance, and lesser sands are the Fourth and Fifth and Gordon Stray. Farther south, in Wetzel, Monongalia, Marion, Doddridge, Lewis, Gilmer, and Ritchie counties, the Catskill sands are important, especially the Gordon, Gordon Stray, Fifth, Bayard or Sixth, Gantz and Thirty-foot. Locally also the Maxton is important. Farther south and west, the Berea is the important horizon. In certain parts of the area, the other Pocono sands, known as the Keener, Big Injun, Squaw, and Wier, produce oil or gas. The Pottsville sands which are occasionally productive are the Cairo and the Salt sands. In Pleasants, Wood, and Ritchie counties, the Allegheny and Conemaugh sands are locally of value. These are, in descending order, the Little Dunkard, the Big Dunkard, and the Burning Springs sand (Upper Freeport sandstone). In summary, the following list of sands from Reger is given:[1]

[1] Reger, D. B., The Copley oil pool of West Virginia, *Bull.* A.A.P.G., **11** (No. 6), 581, 1927.

Pennsylvanian	Monongahela formation:	
	Carroll sand	Uniontown sandstone
	Conemaugh formation:	
	Minshall sand	Connellsville sandstone
	Murphy sand	Morgantown sandstone
	Moundsville sand	Saltsburg sandstone
	Little Dunkard, or First Cow run	Buffalo sandstone
	Big Dunkard sand	Mahoning sandstone
	Allegheny formation:	
	Burning Springs sand	Upper Freeport sandstone
	Gas sand	Lower Freeport sandstone
	Pottsville formation:	
	Second Cow Run sand or Gas sand of Marion County	Homewood sandstone
	Gas sand of Cairo	
	Salt sand of Cairo	
	Cairo sand	
	Gas sand of Rosedale	
	Salt sand of Rosedale	
Mississippian	Mauch Chunk formation:	
	Maxton sand	
	Pocono formation:	
	Keener sand	
	Beckett sand of Milton	
	Big Injun sand	Logan sandstone
	Squaw sand	
	Wier sand	Broad Ford sandstone
	Berea sand	
Devonian	Catskill formation:	
	Gantz sand	
	Fifty-foot sand	
	Thirty-foot sand	
	Gordon Stray sand	
	Gordon sand	
	Fourth sand	
	McDonald or Fifth sand	
	Bayard or Sixth sand	
	Elizabeth or Seventh sand	

Relation of Structure to Production.—A glance at the map (Fig. 11) will show that there is more than a fortuitous parallelism between the long oil producing zones and the major folds. On the Chestnut Ridge anticline and occupying a broad belt on its western flank is a large gas area stretching through four counties more or less continuously. Again, paralleling the

Arches Fork anticline from Monongalia County through Doddridge and western Gilmer counties are long strips of more or less connected oil pools and some gas pools. The Burning Springs anticline in Wood and Pleasants counties shows a very close relationship of structure to production (see Fig. 16). It was this anticline which convinced I. C. White of the validity of the anticlinal theory.

Nevertheless, if the detailed structure maps which have been published by Reger, Wasson, Hennen, Krebs, and other members of the West Virginia Geological Survey are examined, one is impressed by the fact that the oil may occur on any kind of structure and on any portion of an anticline or syncline. While justified in assuming that the main controlling influence is, without doubt, the major anticline, yet minor conditions quite apart from structural conditions explain the particular localization of the oil. These minor conditions are: first, the differential porosity of the sand, and secondly, differential thickness.

Below are two figures (Figs. 20 and 21) taken from Reger's report on the Copley oil pool. They show a fairly close parallelism between the surface structure and the subsurface on the Gordon oil sand. The Grassland syncline lies 3½ miles southeast of the Chestnut Ridge anticline. In this distance, the strata rise at the rate of 100 feet per mile. To the southeast, 6 miles distant, lies the Orlando anticline toward which the strata rise at the rate of 75 feet per mile. The axis of the syncline rises northward at the average rate of 30 feet per mile. It will be noted that the gas lies almost entirely above the 1,650-foot contour, but that the oil does not follow the structure at all. It seems to occupy a belt stretching transversely across the contours and the axis of the syncline. Oil is found as low as the 1,775-foot contour and dry holes as much as 100 feet higher. This is difficult to explain, and Reger believes it is due to the pinching out or absence of sand in some cases, and the nonporous character in others. Illustrations of this kind could be multiplied indefinitely.

Cabin Creek Field.—The Cabin Creek field has been described by Wasson and Wasson.[1] This field is located in Kanawha County in south-central West Virginia. The first well was drilled in 1914, and to date 300 wells have been drilled in the field. It covers an area 12 miles long and from ½ to 1 mile

[1] *Bull.* A.A.P.G., **11** (No. 7), 705–720.

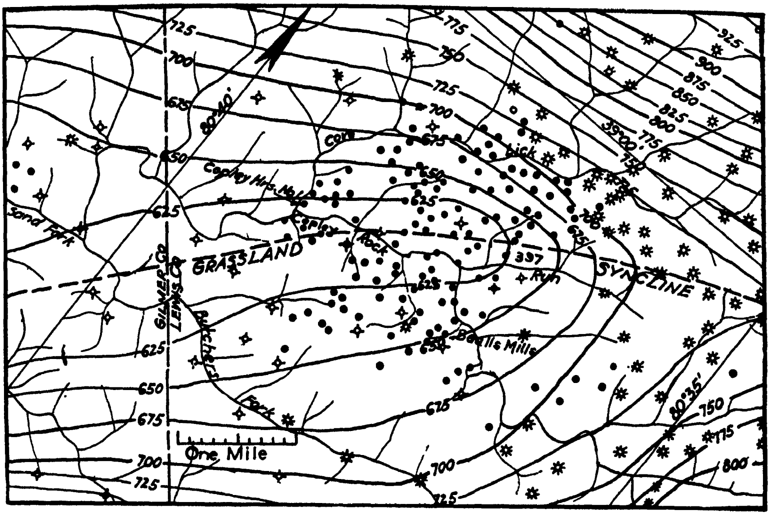

FIG. 20.—Surface structure, Copley oil pool, Lewis and Gilmer counties, West Virginia. (*After Reger, Bull.* A.A.P.G., **6**, 593.)

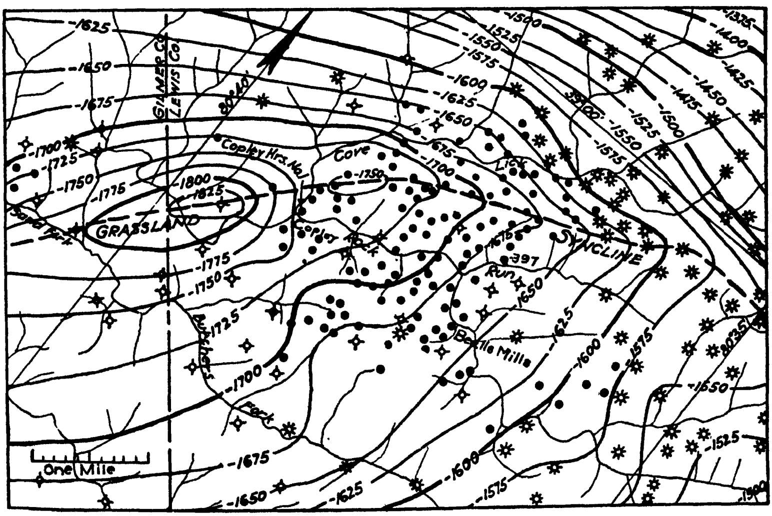

FIG. 21.—Subsurface structure, Copley oil pool, Lewis and Gilmer counties, West Virginia. Contours show elevation of top of Gordon oil sand below sea level. (*After Reger, Bull.* A.A.P.G., **11**, 593.)

wide. The map of West Virginia, showing the main structural axes (Fig. 17, p. 54), shows that the field is located on the east flank of the Appalachian geosyncline and nearly in its deepest part. It lies 75 miles northwest of the Appalachian Mountain front which is faulted 6,000 feet, so that the Cambro-Ordovician limestones lie in contact with the Devonian. With reference to the isocarbs, it lies 15 miles northwest of the 65 per cent line, the 58 per cent isocarb passing through the field.

The surface rocks in this area are of Pennsylvanian age and include members of the Allegheny and Pottsville formations. The thickness of these is 1,400 feet. The Mississippian rocks beneath include red shales, limestone, and sands belonging to the Mauch Chunk formation; the limestone of the Greenbrier (which here is divided into 100 feet called the "Little Lime," 8 to 20 feet of "Pencil Cave," and 200 feet of "Big Lime"); and the Pocono at the bottom with its "Big Injun" sand. At the base of the Pocono is the Berea, characterized in well logs by the appearance of "coffee shale" of the drillers—the Sunbury shale of Ohio. One well penetrated the strata under the Berea, finding 3,000 feet of shale and entering the Corniferous at 5,595 feet. The relationship of these strata, and especially the convergence between certain horizons, is clearly brought out by Fig. 19, p. 57, which is based upon a series of wells from Indiana across Ohio and to the mountain front in West Virginia.

The producing horizon is the Berea sand, which is interpreted as the near-shore deposit of an advancing sea, because of its uniform thickness and wide distribution and purity. In the Cabin Creek pool it averages 35 feet in thickness. An important feature of this sand is its twofold character. Its upper portion is a "cap rock" approximately 15 feet thick of clear, white, hard quartzite which drills up in fine chips instead of in grains. This has a porosity of 4 per cent. The lower portion of the Berea is called the "Pay." It is 35 feet thick in the best part of the field, but pinches out to the southeast, northeast, and southwest. The "Pay" consists of very fine to pebbly quartz sand which is white and well rounded. The pebbly phase is erratic and occurs in thin streaks and patches. The porosity averages 16 per cent.

The structure in the Cabin Creek field is brought out by the map (Fig. 22), which shows the structure on the Berea sandstone as compared to the axes of surface structures. It will be noted that the surface axes do not coincide with the subsurface axes.

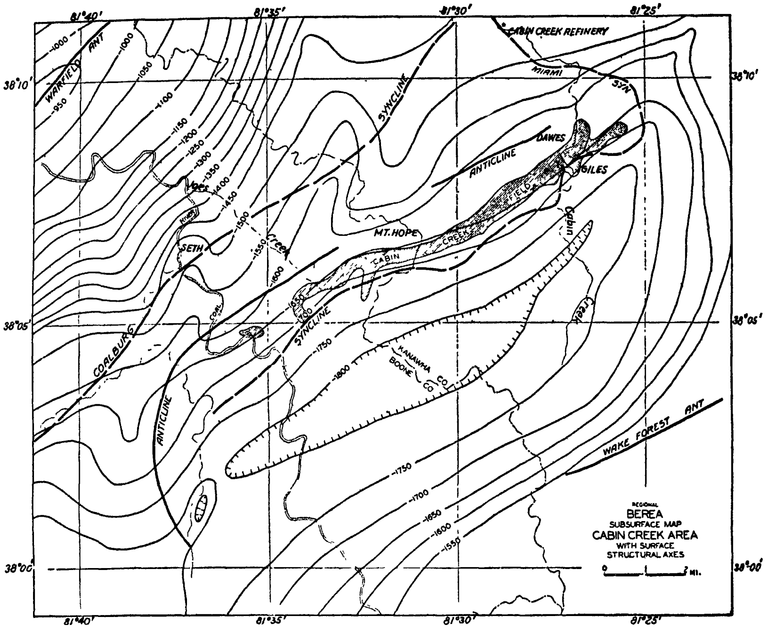

FIG. 22.—Regional Berea subsurface map, Cabin Creek area, with surface structural axes. (*After Wasson, Bull.* A.A.P.G., **11**, opp. p. 713.)

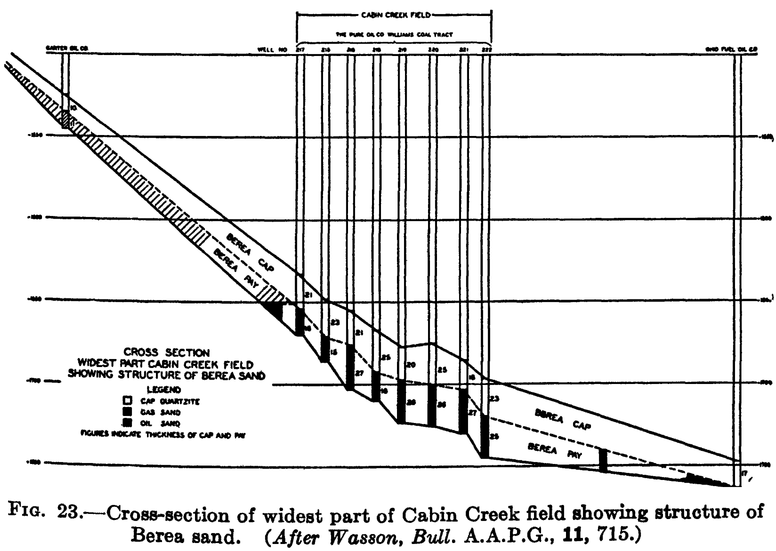

FIG. 23.—Cross-section of widest part of Cabin Creek field showing structure of Berea sand. (*After Wasson, Bull.* A.A.P.G., **11**, 715.)

The surface syncline is shifted to the southeast and the surface anticline nearly disappears on the Berea level. The Warfield anticline farther northwest seems to coincide pretty well. The Coalburg syncline is not present in the Berea horizon. The subsurface map shows that the Berea slopes from the Warfield anticline at the rate of about 85 feet per mile to a basin southeast of the pool. The pool is located on the flank of the anticline very nearly in the bottom of the syncline, but it does follow the structure somewhat by being contained between the 1,600- and 1,700-foot contour lines. Figure 23, which is a cross-section of the Berea sand, shows that it is lenticular and that the "Pay" zone pinches out up the dip. Since there is no water in the sand, the oil extends down as far as the "Pay" lens exists. At the upper edge of the field, gas occurs and continues some distance toward the Warfield anticline. The oil in this pool is exceptionally good because of its lubricating qualities and its high gravity, which averages 47° Bé. Practically the entire pool is controlled by the Pure Oil Company.

Production Statistics.—West Virginia reached its maximum production in 1900, when it produced a little over 16,000,000 barrels of oil. Since then the amount produced each year has been less, but the decrease in production has been slow. For 1927, the production was 6,000,000 barrels and the total production up to the end of that year nearly 356,000,000 barrels. From 1909 to 1920, West Virginia produced more gas than any other state in the union. Its production has steadily increased from 119,000,000,000 cubic feet in 1906 to over 400,000,000,000 cubic feet. During this time, the rock pressure has declined slowly. In 1910, the rock pressure of a large number of wells producing from every horizon showed 479 pounds. In 1919, a similar survey of many wells from all districts and sands showed a rock pressure of only 186 pounds—a loss of 293 pounds in 9 years. If the curve is extended into the future at the same rate, the pressure will be 20 pounds in 1942, although the only reason for believing that it will fall uniformly is the fact that it has done so in the past.

Deep Wells.—Until quite recently the deepest well in the United States was the Martha O. Goff well in northern West Virginia, the stratigraphic record of which is described by I. C. White as follows:

			Thickness, feet	Total, feet
Pittsburgh coal:				
Conemaugh	600	Pennsylvanian	1,150	1,150
Allegheny	290			
Pottsville	260			
Mauch Chunk	260	Mississippian	590	1,740
Greenbrier	65			
Pocono	265			
Catskill	770	Upper Devonian shales	5,823	7,563
Chemung	2,190			
Portage	1,207			
Genesee	288			
Hamilton and Marcellus	1,368			
Corniferous limestone			23	7,586

In this connection, the reader is referred to page 44, where a list of 18 deep wells drilled in the Appalachian fields is given.

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OHIO

A portion of Ohio naturally belongs in the province of the Appalachian geosyncline. For convenience, we may refer to it as eastern Ohio, although it includes some of central Ohio.

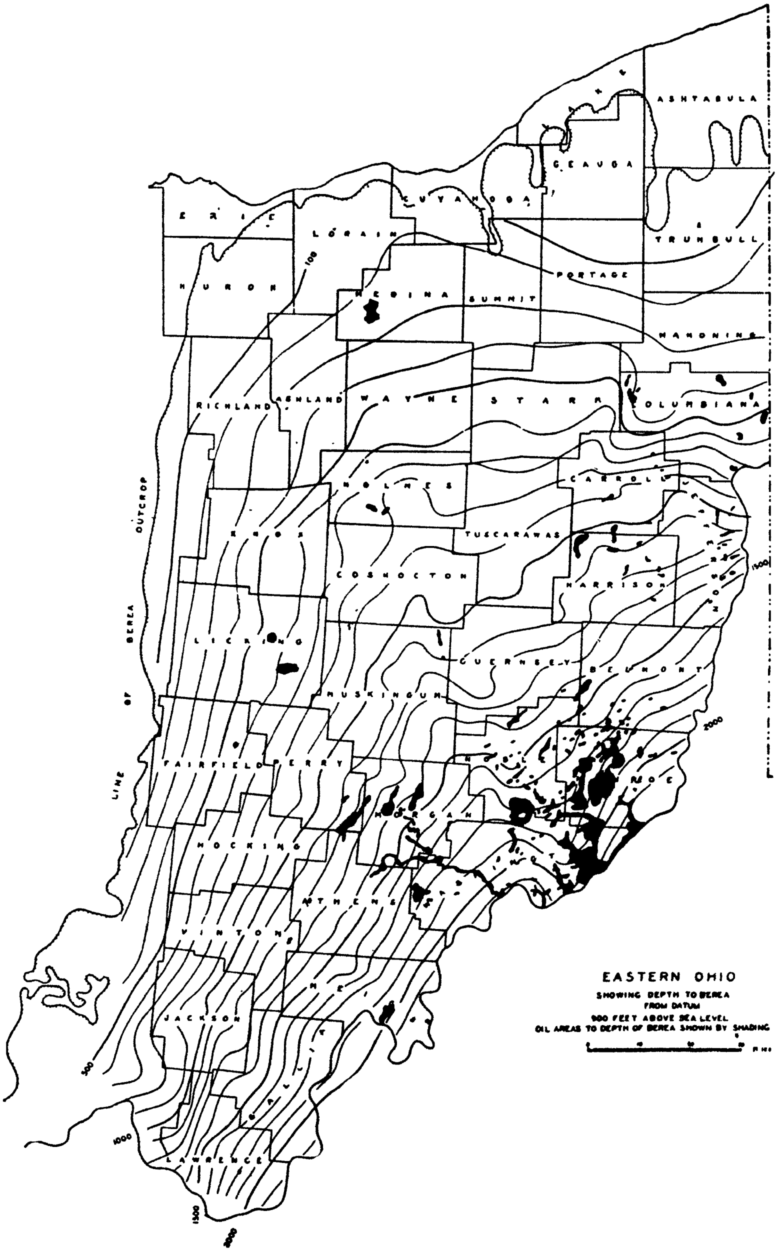

FIG. 24.—Eastern Ohio showing depth to Berea from datum 900 feet above sea level. Oil areas to depth of Berea shown by shading. (*After Cottingham, Bull.* A.A.P.G., **11**, 948.)

The map (Fig. 24) shows the principal oil fields of this portion of the state.

Oil from wells was known in Ohio as early as 1806 when this substance was obtained as an impurity in the brine wells. Occasionally, gas also escaped from such borings and this was looked upon with disfavor, because it was inflammable and therefore dangerous. At some points, the gas seemed to issue from the rock naturally, as a gas seepage. This was true at Cow Run in Washington County and at some localities in eastern Knox County. Perhaps the first well drilled with the express purpose of finding oil was drilled on Duck Creek, near Macksburg, in the southeastern part of the state, where the oil sand was found at the shallow depth of 59 feet. A year later, oil was being found in commercial quantities at Cow Run as well as in Noble and Morgan counties.

It will be noted that the oil and gas fields occur in two more or less distinct areas in eastern Ohio. The reason for this is partly stratigraphical and partly structural. The long, narrow zone of gas reaching from Cleveland through the central part of the state down into Hocking and Vinton counties is the "Clinton gas field." The conditions which account for its location will be made plain presently (Fig. 28, p. 75). The other productive areas of eastern Ohio lie rather close to the Pennsylvania boundary. They make a wide zone trending nearly southwest from northeast and become wider and nearly merge with the Clinton gas field in Athens, Perry, and Hocking counties. The small oil pools in Medina, Holmes, and Licking counties are somewhat exceptional (see Fig. 24). The petroliferous area is 150 miles long and 80 miles wide.

Tectonics.—The controlling tectonic elements which account for the presence of oil in eastern Ohio may be visualized from the preceding discussion regarding adjacent states. The western flank of the great Appalachian geosyncline underlies this part of Ohio. The regional dip is, therefore, to the east and south. The surface rocks dip at the rate of about 35 feet to the mile toward the southeast. It should be pointed out that the dip in the northern part of the area is directed entirely toward the south.

At least three major structural elements modify this large basin structure. One of these is the Burning Springs-Volcano anticline which crosses the Ohio River in southern Washington County and can be traced into central Noble County, western

Guernsey County, and eastern Coshocton County, where it dies out. Adjoining this structural element to the west is a large syncline which is perhaps more prominent than its companion structure. It begins in southern Washington County, trends northwest through western Morgan, western Muskingum, central Coshocton and on into central Holmes County where its influence becomes obscure. This syncline has been called the

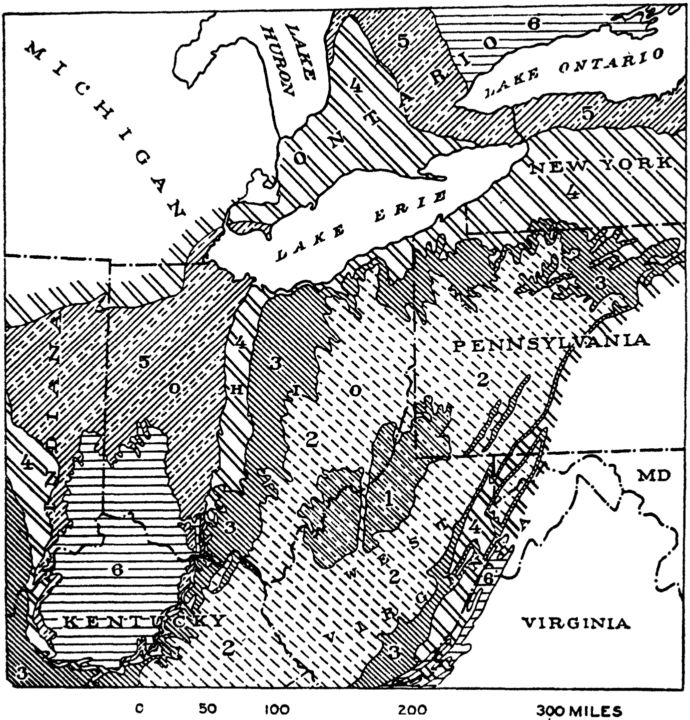

FIG. 25.—Geological sketch map of a portion of the Appalachian geosyncline and adjacent areas. (*After Richardson, Bull.* Geol. Soc. Am., **39**, 545.) 1. Permian; 2. Pennsylvanian; 3. Mississippian; 4. Devonian; 5. Silurian; 6. Ordovician and Cambrian.

Parkersburg syncline and is on the average 150 to 200 feet deep. A structure of lesser importance is the Columbiana anticline which begins in Mahoning County and trends southwestward into Columbiana County and into central Carroll County.

Minor structural features, such as domes, noses, ravines, and terraces, are present in considerable abundance. The maps published in the *U. S. Geological Survey Bulletins* 198, 346,

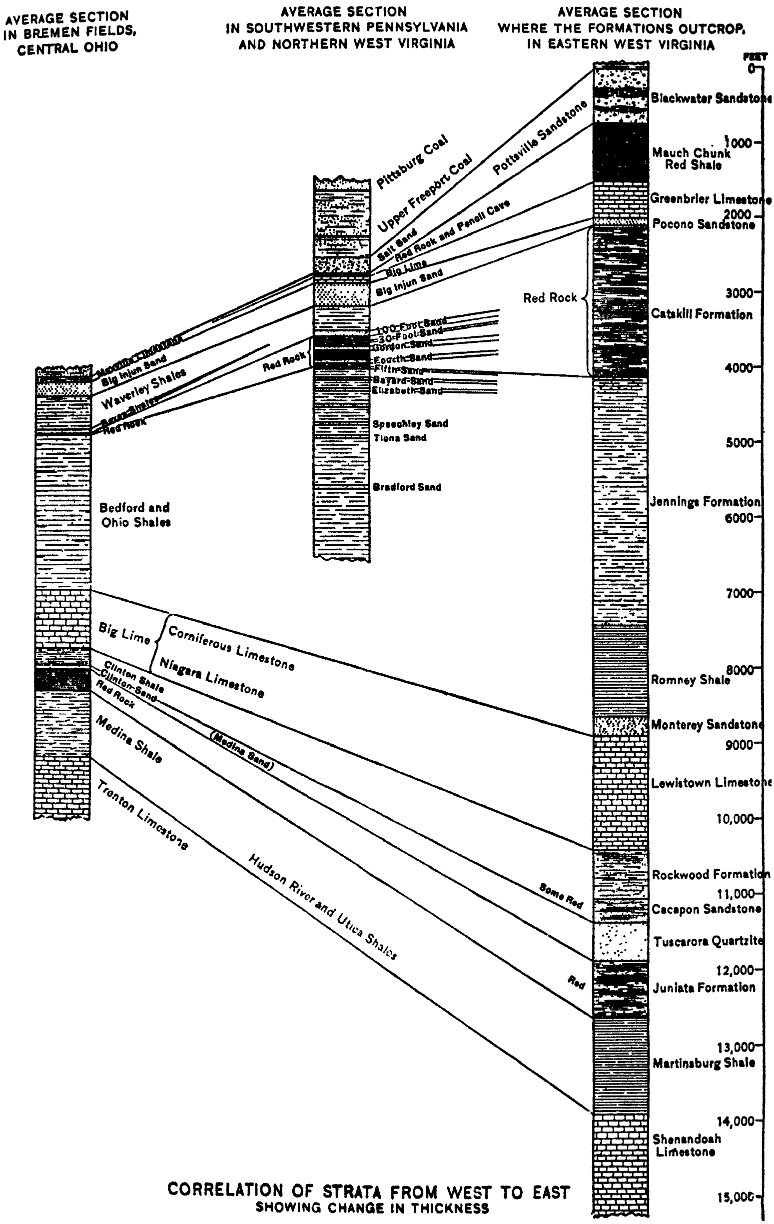

FIG. 26.—Comparative stratigraphic columns in Ohio, West Virginia and Pennsylvania. (*After Clapp, Bull.* Geol. Soc. Am., **28**, 629.)

541 A, 621, H, O, and N, will illustrate these statements sufficiently (see also Figs. 28 and 29).

Stratigraphy.—The succession of rocks which is involved in the surface and subsurface extends down from the Washington formation of Permian age to the Trenton limestone of Ordovician age. Naturally, there are many points of similarity in the section to that which has been described for Pennsylvania and West Virginia. Some new names are introduced, and the thicknesses vary somewhat. The Mississippian is divided into six instead of three formations, as in the adjoining state. The Mauch Chunk is missing because it gradually thins out from east to west and disappears from the section before the Ohio line is reached. The Maxville limestone is probably the equivalent of the Greenbrier limestone. The formations beginning with the Logan and extending down to and including the Berea are, therefore, approximately equivalent to the Pocono. The Bedford is included by some in the Mississippian. The Devonian is divided up somewhat differently. The Catskill, Chemung, Portage, Hamilton, and Marcellus become the Bedford, Cleveland, Chagrin, Huron, and Olentangy shales. The Onondaga and Corniferous limestones are represented by the Columbus and the Delaware.

It will be noted that there are a number of black or dark shale zones in the section. These are important from the standpoint of original source of the oil and gas. It is no mere coincidence that these shales are adjacent to the most productive horizons. The gradual thickening of the Devonian shales was described by White, Bownocker, and others. It produces a convergence of strata between the Berea and the Devonian limestones which amounts to nearly 4,000 feet in the distance across the eastern half of the state. The rate of eastward divergence is equal to about 35 feet per mile, increasing somewhat toward the deeper part of the geosyncline so that it is 50 feet per mile on the eastern border of the state.

Another feature which cannot be overemphasized is the unconformity at the top of the Mississippian. This accounts for a very irregular thickness of the middle Mississippian limestone—the Maxville. It may account also for the complete absence of the overlying Mauch Chunk shales. The disconformity between the Berea and the Bedford also makes for some irregularity in the thickness of the subsurface section in the

oil fields. In the Pennsylvanian coal-bearing system, there are a great many minor interformational unconformities. They probably do not alter the thickness of the section very much, as they compensate each other to some extent. Below is given a generalized stratigraphic section for purposes of reference. The formations that are important to the oil geologist are starred:

GENERALIZED STRATIGRAPHIC SECTION FOR EASTERN OHIO

System	Formation	Thickness, feet	Character
Permian	Washington	400	Shale, sandstone, thin limestones, and coals
Pennsylvanian	Monongahela	250	Shales, thin sandstones, and limestones. Contains five important coal beds of which the Pittsburgh at the base is often used as a key horizon
	Conemaugh	450	Shale, sandstone, and limestone. The Ames limestone is an important key horizon. The Mahoning sandstone at the base often produces oil. Also includes Cow Run and Buell Run sands
	Allegheny	250	Sandstone, shale, clay, and coal. Macksburg, Peeker, and Second Cow Run sands included
	*Pottsville	150	Sandstone and conglomerate with thin clays and a few thin coals. Lower surface very irregular, filling erosion basins in underlying Mississippian formations. Maxton sand included usually at or near the base
Mississippian	*Maxville	100	Limestone with thin shales and sandstones
	*Logan	75	Sandstone with thin shales interbedded. Includes the Keener oil sand
	Black Hand	100	Coarse sandstone and sandy shale. Squaw sand and in some places Big Injun sands
	Cuyahoga	400	Mostly shale with thin sandstones
	Sunbury	30	Dark black shale. Coffee shale of drillers
	*Berea	40	Sandstone. Important oil horizon
Devonian	Bedford	30	Grey, red, and brown shale
	Cleveland	100	Mostly hard black, bituminous shale
	Chagrin	800	Argillaceous, grey shale
	Huron	200	Black and bluish shale. The Huron, Chagrin, Cleveland, and Bedford are usually lumped together by the driller and called "Ohio shale." Varies from 800 to nearly 3,000 feet in thickness progressively from west to east and includes Olentangy
	Olentangy	80	Soft, grey, calcareous shale
	Delaware } Columbus	600	Thinbedded brownish limestone Massive blue and grey limestone. The Delaware and Columbus limestones are not distinguished in wells and are referred to as "Big Lime." Includes Newburg sand and some "stray sands"
Silurian	Monroe	100	Dolomitic limestone. Usually included in "Big Lime" of drillers
	Salina	500	Shale, dolomite, anhydrite, gypsum, and salt
	Niagara	500	Limestone and dolomite. Also usually included in "Big Lime" by drillers
	*Clinton	100	Shale and thin limestones. Includes "Little Lime" of driller
		60	Sandstone varies from 0 to 60 feet. Important gas horizon also produces some oil
		25	Shales
	Medina	350	Red shales with thin layers of sandstone
Ordovician	Cincinnati	1,000	Dark shales with thin limestones
	Trenton		Limestone

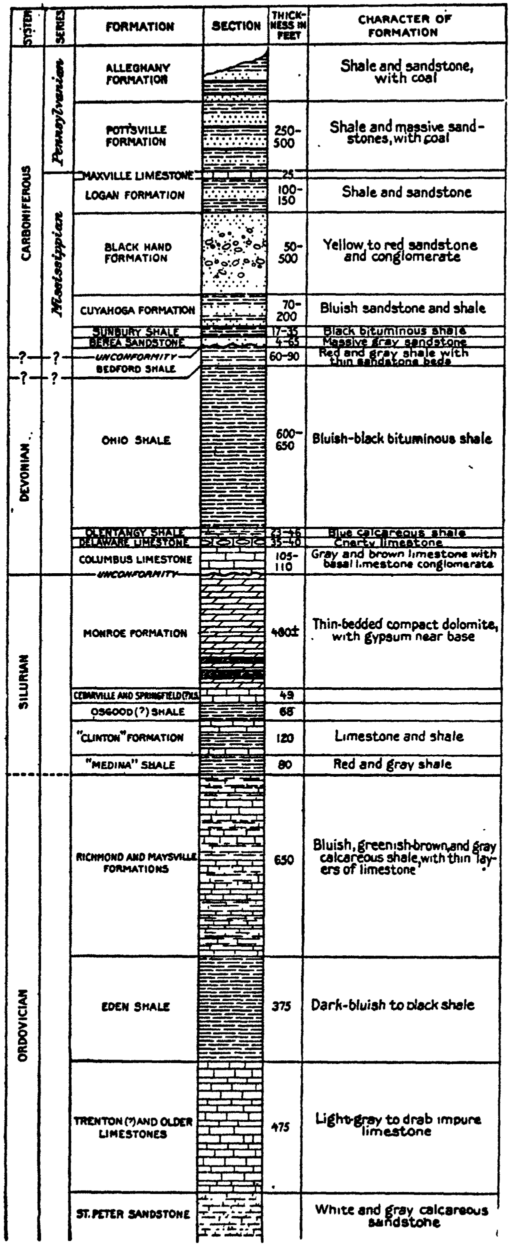

FIG. 27.—Columnar section of rocks in south-central Ohio. (*After Rogers, U. S. Geol. Survey, Prof. Paper* 121, p. 30.)

Producing Horizons.—The number of producing horizons in Ohio suffers by comparison with the great number found in Pennsylvania. Nevertheless, the number of zones in which oil or gas or both are found is considerable. The number of described sands exceeds 15, and of this total about 10 are of importance. In descending order these sands may be listed as follows:

TABLE OF PRODUCING HORIZONS OF EASTERN AND CENTRAL OHIO

System	Formation	Sand	Geological equivalent	Interval to Pittsburgh, feet
Pennsylvanian	Monongahela	Goose Run		100
			*Pittsburgh Coal key bed	0
	Conemaugh	Mitchell		300
		*First Cow Run		350
		Buell Run		
		Mahoning	Mahoning sandstone	
	Allegheny	Peeker		525
		Macksburg		650
		Second Cow Run	Freeport sandstone	700
	Pottsville	Salt Sand group		750
		Maxton	Sharon Conglomerate	950
Mississippian	Maxville	Big Lime	Maxville limestone	975
	Pocono	*Keener	Logan	1,060
		*Big Injun	Black Hand	1,100
		Squaw		1,200
		*Berea	Berea sandstone	1,600
Silurian	Medina	*Clinton	Medina sandstone	
Ordovician	St. Peter	St. Peter	Basal Stones River(?)	

The Goose run and Mitchell sands produce some oil near Marietta. They are patchy and of little importance elsewhere. The First Cow Run sand is productive in Morgan and Washington counties. It is extremely erratic in thickness and distribution. In a very short distance horizontally, it may change from

a thickness of 50 feet to nothing. The texture of the sand also varies greatly from place to place. The Macksburg sand is important only in the vicinity of Macksburg. It is patchy, rather coarse, from 10 to 30 feet thick and, according to Lockett, lies about 650 feet below the Pittsburgh coal. The Second Cow Run sand has produced only in the area where it was first named in Washington County. It is quite unimportant. The Salt sand was named because of the fact that salt water was commonly found in it, being the source of the brines which were secured in southeastern Ohio in the early part of the last century. It produces very small amounts of oil and gas. The Maxton sand is of somewhat greater importance, but, because of its position near the base of the Pottsville, is extremely erratic in its distribution.

The Big Lime has produced considerable oil and gas in Monroe County and southern Belmont County. The oil seems to occur in thin layers of quartz sand which are interbedded with shaly limestone. Very close below the limestone lies the Keener sand. It is productive in the Woodsfield quadrangle and other areas in southeastern Ohio, especially Monroe and Washington counties. The Big Injun is usually separated from the Keener by a few feet of shales. Sometimes they merge, however, and then the whole sand mass is called the Big Injun. It is usually open, coarse, and often conglomeratic. It produces oil and gas in commercial quantities only in Monroe and Washington counties.

The most important horizon for oil or gas is the Berea. This sandstone was evidently deposited in a transgressing sea because it covers all eastern Ohio and is remarkably uniform in thickness and texture. It is thicker in the northern part of the area (50 feet) than in the southern, where it may show as little as 5 feet, or even disappear from the section. Because of the widespread occurrence of this sand, it has become the most important key horizon for subsurface mapping. Production from this sand is commercially important in Lorain, Medina, Trumbull, Columbiana, Stark, Jefferson, Harrison, Belmont, Guernsey, Monroe, Noble, Vinton, Perry, Athens, Morgan, and Washington counties.

Between the Berea and the next horizon, there is a great thickness of shales and limestones which do not yield oil or gas in quantity. This mass of rocks is over 3,000 feet thick in the

southeastern portion of the state, but gradually becomes less toward the north and west. The Clinton below the shales, therefore, lies within drilling depths in a broad zone of counties running nearly north and south through the state. Figure 28 shows the area in which the Clinton has been found productive and also, by means of contours, the surface structure of eastern Ohio on that horizon. It should be pointed out, however, that these contours do not reflect the structure as accurately as the map based on the Berea, which is shown in Fig. 24, because the number of wells drilled to the Clinton are far fewer. The gas field in the Clinton sand running from Cleveland to Jackson County is considered by Bownocker to be the richest that has ever been discovered. The usual thickness of the sand in this area is from 10 to 40 feet although it sometimes measures 100 feet. It is found at a depth between 2,000 and 2,700 feet.

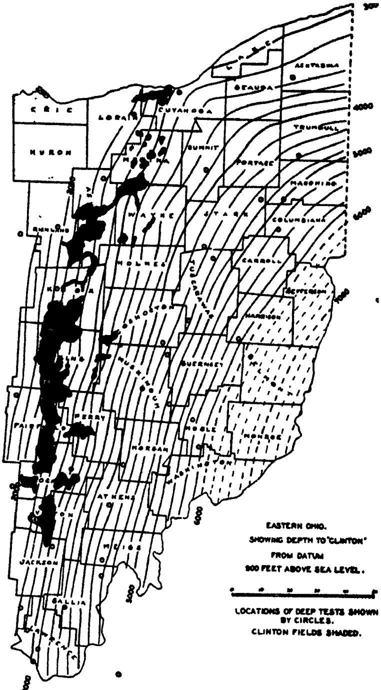

FIG. 28.—Eastern Ohio showing depths to Clinton from datum 900 feet above sea level. (*After Cottingham, Bull.* A.A.P.G., **11**, 949.)

What may prove to be production from the Oriskany horizon has recently been found in the Cambridge gas field in western Guernsey County. It lies from 115 to 165 feet below the top of the "Big Lime" (Devonian and Silurian limestones). Another unusual sand in the Big Lime has been found in the vicinity of Cleveland. This is called the "Stadler" sand and lies at a depth of 1,160 feet below the top of the limestone.

Relation of Production to Structure.—The structure of the oil sands of eastern Ohio is pretty well understood. Quite a number of maps which show the structure of some of the oil fields in that area have been published in recent years. In Fig. 29 is repro-

duced a map taken from an article by Cottingham on "Structural Conditions in Portions of Eastern Ohio."[1] It shows an area in Guernsey, Noble, Belmont, and Monroe counties, or essentially the same area that is described by Condit in Bulletin 621 of the U. S. Geological Survey. Condit made a map showing the subsurface structure on the Berea, and Cottingham's map is based on the Pittsburgh coal horizon. The two maps show

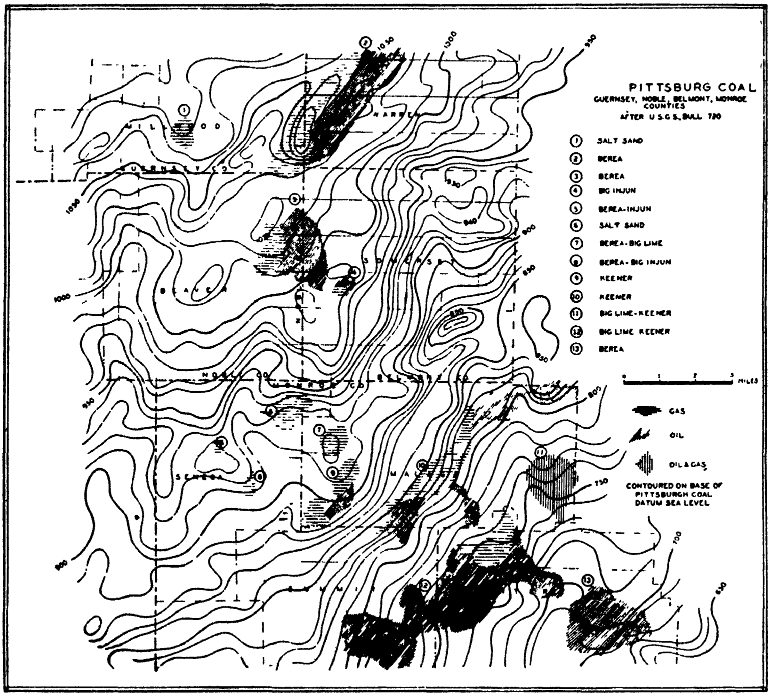

FIG. 29.—Structure on Pittsburgh coal in Guernsey, Noble, Belmont and Monroe counties. (*After Cottingham, Bull.* A.A.P.G., **11**, 955.)

more correspondence than might be expected, and it is interesting to note that the map was made by means of a convergence sheet. In the area shown, there are 12 producing sands, half of which are important in that district. A careful scrutiny of the map shows only one pool that agrees with the anticlinal theory. It does not show on Fig. 29, but lies about 6 miles farther west on the Chaseville anticline. Of the others that show on Condit's map, three are located on noses. They are the Barnesville

[1] *Bull.* A.A.P.G., **11** (No. 7), 945–958.

remarkable feature brought out by the investigation and one which has a *bearing on the migration theories of gas and oil* is the fact that the gas in a sand 1,850 feet higher than the Clinton carried practically the same proportion of helium (0.39 per cent).

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EASTERN KENTUCKY

Oil was first discovered in Kentucky in the year 1819, in what is now McCreary County, in a well which was being drilled for salt. Like other wells in other parts of the Appalachian geosyncline, this showing of oil was treated with disfavor and the beginning of a new industry postponed 40 years. Another phenomenal well for those times was one drilled near Burkesville, in 1828, which caught fire and produced a burning fountain as

well as a burning river, for the oil which flowed away on the water also burned.

The productive area in eastern Kentucky, which will be considered in this chapter, is shown on Fig. 32. It is approximately 150 miles long in a direction running parallel to the trend which is from northeast to southwest, and 35 miles wide at the widest point. The counties which are important producers in this zone are as follows: Lawrence, Johnson, Bath, Menefee, Powell, Lee, Magoffin, Breathitt, Owsley, Floyd, Knott, Clay, and Knox. This list may be shortened when it is limited to those in which production was large. The Campton pool in Wolfe County, the Irvine pool in Estill County, the Ashley pool in Powell County, and the Big Sinking pool in Lee County stand out as the major pools of the whole region.

Tectonic Elements.—The fundamental and controlling structural element in eastern Kentucky is the Appalachian geosyncline. The axis of this geosyncline enters Kentucky in eastern Pike County, trends nearly due west through Floyd, to Breathitt County, then turns southwest and passes through Perry, Clay, and central Knox counties, and leaves the state in south-central Whitley County. South of this axis a distance of 30 to 40 miles lies the well-known Pine Mountain fault. The location of this structural element is shown on Fig. 33, which is taken from Fiske's report on the oil and gas fields of eastern Kentucky.[1] Fiske believes this structure began as an anticlinal fold, broke at the top, and terminated in an overthrust fault which has a throw of more than 2,000 feet.

Some thirty miles north of the axis of the Appalachian geosyncline and trending more or less parallel to it lies the Irvine-Paint Creek fault. This fault has a displacement of 200 feet along most of its course in Powell and Estill counties. It dies out toward the east and becomes the Warfield anticline of West Virginia. To the west, its continuation and characteristics are not well known. An important cross-fold which trends nearly north and south is called the "Paint Creek uplift." It passes through Elliott, Morgan, and Magoffin counties into Floyd County.

Stratigraphy.—The stratigraphy of the eastern Kentucky oil and gas fields may be expected to show considerable similarity

[1] FISKE, L. E., The relation of structure to production in five oil and gas fields of the Kentucky eastern coal field, *Bull.* A.A.P.G., **11** (No. 5), 477.

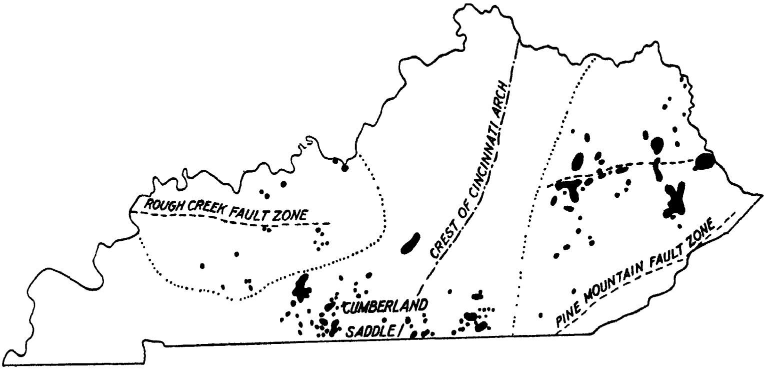

FIG. 32.—Sketch map showing oil pools of Kentucky.

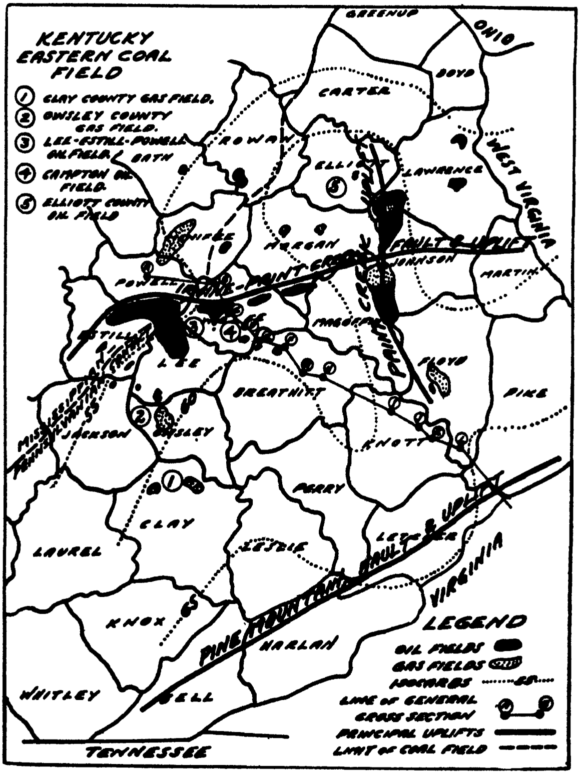

FIG. 33.—Major structural elements in eastern Kentucky. (*After Fiske, Bull.* A.A.P.G., **11**, 479.)

to that of West Virginia. The following table of formations will give the reader an opportunity to compare the succession of rocks in the two states:

GENERALIZED STRATIGRAPHIC SECTION FOR EASTERN KENTUCKY

System	Formation	Thickness, feet	Character
Pennsylvanian	Upper Pottsville	400	Shales with a few thin sandstones and coals
	Lower Pottsville	100 to 1,200	Conglomerate, sandstone, a few thin shales and coals. Very thick along Pine Mountain fault. Thins gradually to northwest
Mississippian	Mauch Chunk	200	Shale and sandstone. Important *unconformity* at top. Contains Maxon sand. Some red shale
	St. Genevieve	150	White oolitic limestone. Big Lime of drillers
	St. Louis	5	Grey and white compact limestone
	Waverly	400	Alternating shales and sandstones. Berea at base. Contains also Wier sand
Devonian	Chattanooga	100 to 700	Black shale. Converges from southeast to northwest 700 feet to 100 feet
	Corniferous	50	Impure often porous limestone. Sometimes with true sand inclusions in lens form as beneath south end of Lee-Estill-Powell area
Silurian	Niagara	180	Impure magnesian limestone. Often porous and sometimes contains irregular true sand inclusions which may be called Clinton sand
Ordovician	Richmond	600	Shales, thin limestones, and some sand

The Richmond formation is the lowest formation of interest in eastern Kentucky inasmuch as no production has been found below that horizon to date. It is the uppermost division of the Cincinnatian series, which includes in descending order the

Eden and Maysville. These formations crop out in the Central Blue Grass area where they are about 700 feet thick. In Wolfe and Morgan counties a little production is obtained from the Cincinnatian series in the "Caney" sand.

The Niagara limestone includes the original "Clinton" limestone or what is now called the "Brassfield." The Brassfield is a rather thin bed 10 to 20 feet thick which is found on both sides of the Cincinnati arch. It is readily recognized in the driller's log by the fact that it is red and contains the "flax-seed" iron ore. The true Niagara is a blue or grey magnesian limestone which has in places thin interbedded shale and sometimes true sandstone lenses. In the well logs, it is difficult to separate the Niagara from the Corniferous. These two together are thickest in the region about the Irvine-Paint Creek fault, where they reach a thickness of probably 250 feet. The uppermost part of the Niagara is called the "Louisville" limestone from its outcrops near Louisville, Ky. This limestone does not produce oil or gas in the eastern part of the state (see Fig. 41, p. 113).

The Corniferous or Onondaga limestone (see Fig. 42, p. 114) is the most important formation in the whole section, because it is the principal producing horizon. On the outcrop it is a thick-bedded, massive, magnesian limestone with many inclusions of chert. In the petroliferous areas, the topmost three to five feet is dark brown, hard, and bituminous, sometimes alternating with thin shales. This is the "cap rock" of the driller. Below this rock occurs a hard, flinty, massive limestone below which there is grey and white limestone. Oil seems to occur in all these parts at different places. The following important fields of eastern Kentucky derive their oil entirely or in part from the Corniferous: Ragland, Menefee gas pool; Irvine, Campton, Ashley, and Big Sinking oil pools.

The black shale found above the Corniferous is the stratigraphic equivalent of the Chattanooga of Tennessee, of the Ohio shale in Ohio, and probably of the Genesee of New York. Besides that, it is also the equivalent of the Sunbury in places. For along the western edge of the Eastern coal field, the Bedford shale and the Berea sand of the Waverly formation pinches out and the Sunbury comes to rest immediately above the Devonian black shale. This shale is very bituminous and, because of that fact, is generally conceded to be the original source of the oil and gas in eastern Kentucky. A dissenting

voice to this conclusion is that of Jillson, the state geologist of Kentucky. He believes that the production from stray sands in the shale, which is always gas under small pressure, is an argument against the assumption.

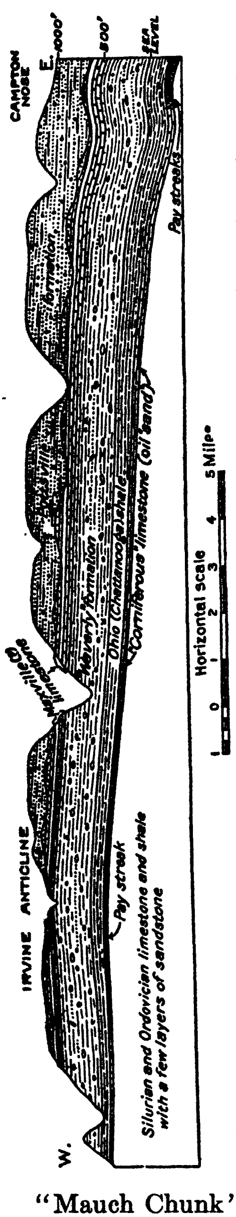

FIG. 34.—Cross-section from Irvine to Campton, Kentucky, showing the dip and thickening of formations to the east. (*After Shaw, U. S. Geol. Survey, Bull. 661.*)

The Waverly is divided by Jillson into the following four members, beginning at the base: Kinderhook, Cuyahoga, Logan, and Warsaw. The whole formation is made up of shales, limestones, and sandstones. They are more sandy toward the northeast and more calcareous toward the southeast and the northwest. They underlie the eastern part of the eastern area and there contain many sands, very few of which are of economic importance. The two important ones are the Berea and the Wier.

The limestone of middle Mississippian age is called "St. Genevieve" limestone in eastern Kentucky although sometimes a very thin representative of the St. Louis limestone, so characteristic west of the Cincinnati arch, is found. In the drill records, it is referred to as the "Big Lime." Although it is quite likely to have oil in cavities along the outcrop in northeastern Kentucky this limestone cannot be considered an oil horizon. At some places, there is a thin sandstone about midway within the Big Lime which produces gas in Floyd, Knott, and Martin counties. This limestone shows great variation in thickness, due largely to the presence of an unconformity at the top of the Mississippian which has cut entirely through the Mauch Chunk and into the underlying Big Lime (see Fig. 34).

"Mauch Chunk" is the name given to a series of red shales, white sands, and thin limestones and dark-colored shales at the

base. It is extremely variable in thickness, varying from nothing to over 250 feet. The reason for this is the same as the one just given for the variable thickness of the limestone below it. In southern Johnson, Martin, Floyd, and Pike counties, oil and gas are secured from a sand intercalated between red and green shales. This is the "Maxon" sand of the drillers. Production is small but long lived.

The Pottsville formation can be divided into two parts on the basis of lithology, the lower section containing mostly conglomerates and sandstones and the upper section consisting of shales and coals with occasional thin sandstones. The lower, coarse portion shows a great variation in thickness. It is thickest near the source of the material which was to the east and southeast. The angle of cross-bedding is uniformly 45 degrees west, which seems to indicate its derivation from the east. Over 1,200 feet were accumulated along the Pine Mountain fault, whereas in the region of the Irvine-Paint Creek fault only about 250 feet are found. The upper, less-coarse portion is also thickest near the southeastern corner of the state, becoming somewhat thinner toward the northwest; but the rate of thinning is much less than for the lower portion. In addition to thinning, there is also less of it because of erosion. Near the Irvine-Paint Creek fault nearly all of it has been removed by erosion.

In Floyd and Knott counties, this formation carries oil and gas in three different sands; in Knox County, it also produces petroleum; and four different horizons are encountered there in the Pottsville.

Producing Horizons.—Kentucky has almost as many horizons which produce oil and gas as has Pennsylvania. Very few of them, however, produce over a wide area, and the number of those which produce large quantities is still further limited. In the table below are listed all of the sands that have been found to contain oil or gas in eastern Kentucky. Those of importance are starred. The Corniferous should be double starred, as it produces more than 50 per cent of the oil in this part of the state. The Berea and the Wier together produce perhaps 30 per cent.

As stated previously, the Corniferous is the most important horizon. It produces from porous zones or from true sand lenses at various depths within the mass. For instance, in the Lee-Estill-Powell field it produces from three different zones. In the best part of the field, only the third pay is valuable, since the first and second carry water. In the Owsley County gas

TABLE OF PRODUCING HORIZONS IN EASTERN KENTUCKY

System	Formation	Sands	Counties where productive
Pennsylvanian	Pottsville	Beaver Horton Pike	Floyd and Knott Floyd and Knott Floyd, Knott, and Magoffin
	Pottsville	Wages Jones Epperson	Knox Knox Knox
Mississippian	Mauch Chunk St. Genevieve	Maxon Big Lime	Floyd and Knott Floyd, Knott, and Martin
	Waverly	Big Injun *Wier *Berea	Floyd, Knott, Martin, and Clay Magoffin, Morgan, Johnson, and Lawrence Johnson and Lawrence
Devonian		*Corniferous	Bath, Rowan, Menefee, Powell, Morgan, Wolfe, Lee Estill, and Breathitt

field, the Corniferous carries gas near the top and oil near the base. Where true sand inclusions occur, some remarkable wells are found as, for instance, beneath the south end of the Lee-Estill-Powell field.

The Berea sand is a source of commercial production in Lawrence and Johnson counties, but efforts to find oil in it elsewhere have resulted in failure. It is a water-free sand, consists of white quartz grains, and varies greatly in porosity and thickness.

The Wier sand takes second rank in eastern Kentucky. It is a fine-grained quartz sandstone, somewhat lenticular in character and, according to Fiske, does not extend a great distance beyond the Paint Creek uplift. Most of the production occurs above a shale break in the sand and particularly where this portion of the sand is thick. The oil occasionally found in the lower portion of the sand is not important.

The *Big Injun* sand produces gas only. It is somewhat erratic in its occurrence and may be missing altogether. Also the sands which correspond in position to the Keener and Squaw of West Virginia and eastern Ohio frequently occur near this sand or merge with it. Where productive in Floyd County it varies in thickness from about 40 to 83 feet.

The *Big Lime* is also variable in thickness. It produces from porous zones or from interbedded thin sandstones. The

stone is grey or white and compact in most places, though occasionally there is much oolitic limestone present. Because of its lithology, it is a very useful key horizon in interpreting well logs. The Big Lime produces very little oil, but as a source of gas it seems to have strong possibilities. Much gas has been found in Floyd and Knott counties in this horizon, but to date this has not been utilized.

In Floyd and Knott counties, where the *Maxon sand* is productive, it is found between red and green shales of the Mauch Chunk formation. There it may occur as a single or a double sand varying in thickness from 50 to 100 feet. Both oil and gas have been found in it, but the gas seems to be more common.

The outstanding characteristic of the *Pottsville* formation is its variability in lithology and thickness. Sands may be found in it at almost any horizon. For that reason, such sands cannot be traced any great distance. Over limited areas, they have been found traceable in the well logs of Floyd and Knott counties, and have been given names which are in descending order: Beaver, Horton, and Pike. Of the three, the uppermost is the thickest. All of them produce both oil and gas. The oil is a green, high-gravity, Somerset grade crude. This statement should be modified somewhat for the oil in Magoffin County, which comes from the Pottsville sands, is black and of low gravity which may be accounted for by the nearness of the outcrop of the sand.

In Knox County, where the Pottsville also produces oil and gas, the sands have been given different names and probably for the good reason that they occur at very different horizons from those described above. They are in descending order the Wages, Jones, and Epperson. In places, a fourth sand is found which is called the "Salt sand." The Jones seems to be the most consistent oil producer. It varies in thickness from a few feet to 150 feet or more.

Relation of Production to Structure.—In the fields of eastern Kentucky, there seems to be a more definite relation of production to structure than has been recorded for the adjacent states. Yet the relationship is not as perfect as theoretical considerations demand. A glance at the map which shows the distribution of oil and gas in eastern Kentucky (Fig. 32) shows that the most prolific and largest pools are centered about the most pronounced structural feature of the district, the Irvine-Paint Creek fault and

its continuation, the Warfield anticline. It appears that the oil and gas migrated up the dip from the axis of the Appalachian geosyncline toward the northwest and tried to reach the highest part of the structures it encountered. If a study is made of the detailed maps of this part of the area which have been published by the State Geological Survey, and some others, it is noted that accumulation did not take place entirely on the highest part of the minor structures. Instead, accumulation took place on terraces, noses, and even in synclines and basins. Relative water saturation of the sands cannot explain this condition in every case and the conclusion is that differential porosity again has played the leading rôle. Fiske[1] presents the following conclusions:

It will be noticed that the Irvine sand pools (Estill, Lee, Wolfe, and Morgan counties), which produce about 60 per cent of the oil produced in the state, lie along the flank of the Irvine-Paint Creek uplift which parallels the Irvine-Paint Creek fault. It will be further noticed that the Wier pools of Lawrence, Johnson, and Magoffin counties (producing 30 per cent) lie along the axis of the Paint Creek uplift. Other production in eastern Kentucky is of very minor importance compared with these pools. This close relation of production to uplift, bears out the theory that oil was formed, during, and as the result of, folding, rather than having been formed prior to the fold and having subsequently migrated into it. It may be generally stated, therefore, that folding seems essential to the accumulation of oil in eastern Kentucky, but that the degree of folding must not pass beyond a certain point (which point is first exceeded by the deeper sands) lest the hydrocarbons be changed to gas or lost. The most favorable formations for producing oil are those which are stratigraphically high, geologically young, and moderately folded.

To these general statements he adds:

. . . but the principal control of production (in the Clinton and Corniferous) will be the location of the porous streaks in the limestone, or the position of the included sand lenses.

Regarding the Berea, he says:

"Production seems to be in general synclinal, but not always."

Lee-Estill-Powell Oil Field.—One of the largest and most important producing areas is described by Fiske under the caption

[1] Fiske, L. E., The relation of structure to production in five oil and gas fields of the Eastern coal field of Kentucky, *Bull.* A.A.P.G., **11** (No. 5), 477 *ff*, 1927.

of Lee-Estill-Powell oil field. The name furnishes information as to its geographic location. Structurally, it lies along the south flank of the Irvine-Paint Creek uplift, according to Fig. 33, p. 83, which is taken from Fiske's article. The Irvine-Paint Creek fault which bounds production on the north has a displacement

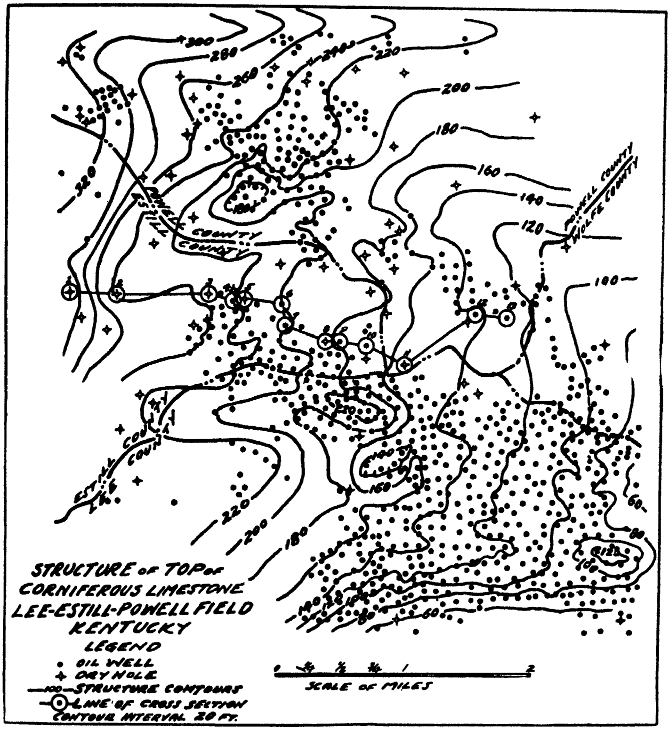

FIG. 35.—Structure on the top of the Corniferous limestone, Lee-Estill Powell field, Kentucky. (*After Fiske, Bull.* A.A.P.G., **11**, 484.)

of about 200 feet with the downthrow on the south. An anticline parallels the strike of the fault and pitches toward the east. It is faulted on the west end by the Estill Furnace fault which has the downthrow on the north side producing a graben between the two faults. Production in this field comes from the Corniferous limestone which has a thickness of about 100 feet and has three porous zones in it. It will be noted that production does appear on the anticlinal fold south of the fault, but that it is by no means limited to that fold. In fact, the best part of the area lies on a subordinate anticlinal nose which parallels the boundary between Wolfe and Lee counties. The synclinal tract between

the two anticlines has considerable production also. Furthermore, it will be seen that a good many dry holes dot the structure where it should be most favorable. All this refers to the map contoured on the top of the middle Mississippian limestone, here called the "St. Louis" limestone. Figure 35 shows the subsurface structure based on the producing horizon. The correspondence between the two maps is fairly close. The anticline in Lee County is broader and not so well defined, but the syncline to the north of it has not changed its aspect much.

In this field, the production on some large leases has been 3,500 barrels per acre up to date and the ultimate total production is estimated at 5,000 barrels per acre.

Production Statistics.—The production of oil in Kentucky reached a peak in 1922 when over 9,000,000 barrels were produced. Since then, the production has dropped some, but not very much, and is still well above 6,000,000 barrels per year. Most of the petroleum is of a green color, with a fairly high gasoline content, and with a gravity between 32 and 38° on the Beaumé scale. The lowest gravity oil has a gravity of 22° which is the Ragland pool oil, while the highest is from Johnson County, and shows a gravity of 51.6°.

Natural gas has been found in seven counties in eastern Kentucky. These are Floyd, Knott, Magoffin, Menefee, Owsley, Martin, and Johnson counties. Jillson estimates that the possible amount of gas which might be utilized from these pools amounts to not less than 40,000,000 cubic feet.

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CHAPTER III

THE CINCINNATI ARCH PROVINCE

The second group of oil and gas fields, according to the tectonic classification, is the group which is related to the Cincinnati arch. This arch extends from northern Alabama in a direction nearly north to northern Ohio and into Ontario, Canada. It was formed in one of the periodic shrinking spells of the earth's crust[1] which may be called for our purpose the "Taconic Revolution." At the time of this great period of crustal unrest, a fairly large land mass may be pictured along the eastern border of our continent, called "Appalachia," and a somewhat larger land mass in eastern and central Canada, called "Laurentia." Stretching west for great distances, only water is seen—an epicontinental sea covering the Eastern states, the Mississippi Valley states, and others beyond. In this sea, sediments had been accumulating during long periods of time—the Georgic, Acadic, and Ozarkic (of Cambrian time) and the Canadic, Ordovicic, and Cincinnatic periods (of Ordovician time). These six periods represent six distinct transgressions of the sea and corresponding emergences of portions of the areas submerged, The sediments laid down in the Mississippian Sea were mostly limestone and dolomites (magnesian limestones). It was during the Lowville stage of the Ordovicic period that the first signs of a differential subsidence is noted in this sea, and the first warnings of the impending revolution.

A portion of the axis of the Cincinnati arch remained elevated, while the surrounding regions slowly subsided. This portion is located in central Tennessee and has been called the "Nashville dome." It remained above the waters of the epicontinental sea during the subsequent Trenton stage when our continent suffered the most extensive submergence ever known. In the next stage, called the "Lorraine" or "Maysville," and especially in the Richmond stage of the Cincinnatic period, it became con-

[1] In this connection the reader is referred to Daly's stimulating book "Our Mobile Earth." He will also find food for thought in the "Theory of Continental Drift," published by the A.A.P.G. in 1928.

siderably enlarged. During these stages, also, the best-known portion of the arch remained elevated by differential subsidence. This portion lies in central Kentucky and has been called the "Jessamine dome," having its highest point near Nicholasville in Jessamine County. No doubt, the more northern extensions of the arch in western Ohio, eastern Indiana, and southwestern Ontario developed during the Cincinnatic period but subsided

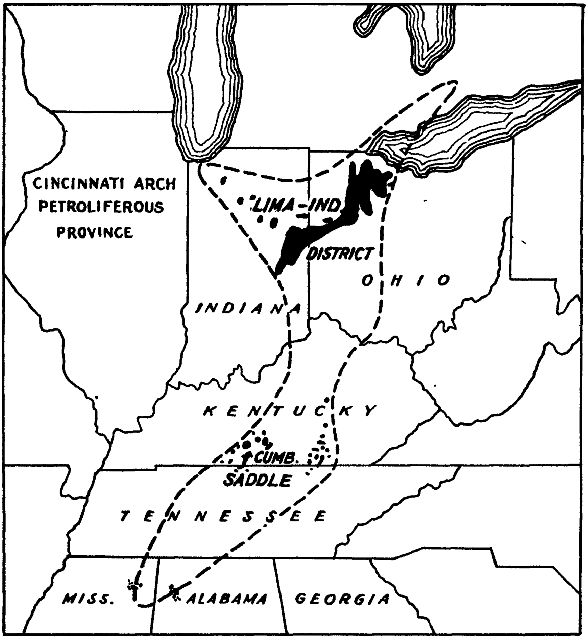

FIG. 36.—The Cincinnati arch petroliferous province. Shaded areas indicate oil- and gas-producing areas, stippled gas only. Province outlined by dashes.

somewhat more than the portions of the arch previously described. Hence, they are covered by sediments of Cincinnatic age and with even younger sediments farther north. The subsidence of the North Atlantic Ocean, contemporaneously, finally culminated in a series of thrusts which produced the Taconic Mountains of New England and contemporary ranges of eastern North America.

Stratigraphy.—The rocks which may be found in the oil fields which are associated with this great arch belong to the older periods of the Paleozoic era. They belong chiefly to the Cambrian system of the old classification (Acadic and Ozarkic

systems of the newer classification), the Ordovician (Canadic, Ordovicic, and Cincinnatic), and the Silurian. In Kentucky are found, also, the Devonian, and Mississippian, represented on a deep saddle of the arch (see Fig. 41, p. 113). Beginning with the Silurian, there are a great many gaps in the record and, therefore, many unconformities in the section. For instance, the older Silurian or Anticostian series is missing and the upper Silurian or Cayugan series is present only on the northern flanks. Of the Devonian formations, all those belonging to the Paleodevonic, the Helderbergian, and the Oriskanian series are missing. The middle and upper Devonian series are present only in the Cumberland saddle in Kentucky and on the northern flanks.

The Mississippian rocks appear again in full thickness on the flanks of the arch and in the Cumberland saddle of southern Kentucky. They present a difficult problem for correlation because they consist of sediments which vary considerably on the two sides of the arch. The thickness, as might be expected, varies also but here there is some systematic variation, for the strata become thicker as they attain a greater distance from the axis of the arch. This is also true, of course, of the Silurian rocks which are missing over perhaps 50 miles of the narrowest part of the axis, and of the Devonian rocks which are represented only by the black Chattanooga shales on the axis in the Cumberland saddle. Both of these systems thicken rapidly to the east and west. Pennsylvanian rocks are not found on the arch.

Producing Horizons.—In the fields of the Cincinnati arch petroliferous province, the Devonian, Silurian, and Ordovician systems furnish the important oil and gas horizons. The Mississippian formations furnish a small amount of oil. The Devonian horizon is the Corniferous, which is so valuable in eastern Kentucky. It produces also in western south-central Kentucky. The Niagara limestone of middle-Silurian age produces most of the oil in Kentucky on the western side of the arch. The Ordovician has a number of horizons. Of these, the so-called Trenton is by far the most important because of the large production obtained in the Lima, Indiana district. In Tennessee, most of the oil found to date has also been associated with Ordovician horizons.

The oil and gas fields which will be considered in this chapter include western Ohio and eastern Indiana (Lima-Indiana dis-

trict), south-central Kentucky, and Tennessee (Cumberland Saddle district), and the Alabama and Mississippi districts.

LIMA-INDIANA DISTRICT

As in the case of so many oil and gas districts, it is found that in western Ohio the industry started because of seepages of gas. These were known for a long time before specific mention is made of them in print. Along the Blanchard River, gas escaped at the surface. It was also noted in water wells, especially at the town of Findlay. In 1838, gas was first used for illumination purposes in a residence in Findlay, and that may be considered the beginning of the industry in that part of the state.

The production of oil probably started with the Lima well, located in Allen County, which was completed in the spring of 1885. Its yield amounted to 15 barrels per day. Many wells in Wood and Hancock counties which had started as gas wells began making oil. In 1886, a well drilled near North Baltimore encountered a different grade of oil and this encouraged further drilling. The oil from this well had a gravity of 41° Bé. Soon wild-cat wells were drilling in every direction and the boom was on in full force. In 1886, a year and a half after the first oil well was drilled in, the production of the Trenton field amounted to over 1,000,000 barrels. In its final, fully developed condition, the field extended from Toledo in Lucas County through Ottawa, Sandusky, Wood, Hancock, Allen, and Auglaize counties, into Mercer County (see map of the field, Fig. 37). It crosses the state line into northeastern Indiana where it covers parts of Adams, Jay, Wells, Blackford, Huntington, and Grant counties.

Structural Conditions.—The major tectonic element in the Lima-Indiana oil and gas district is the broad arch of the northern extension of the Cincinnati arch. Orton was the first to point out this structural control and showed it in the first map ever made to show structure by contour lines. Superposed on the broad arch are several domes of considerable size as, for example, at Findlay and at Bowling Green. In Indiana, the arch shows a broad, terraced nose pitching toward the northwest. These features have all been instrumental in trapping the oil; nevertheless, they are not alone responsible for the great accumulations of oil and gas which have been found here. The element of differential porosity enters again as a very important modifying influence, for otherwise one would expect to find oil and gas

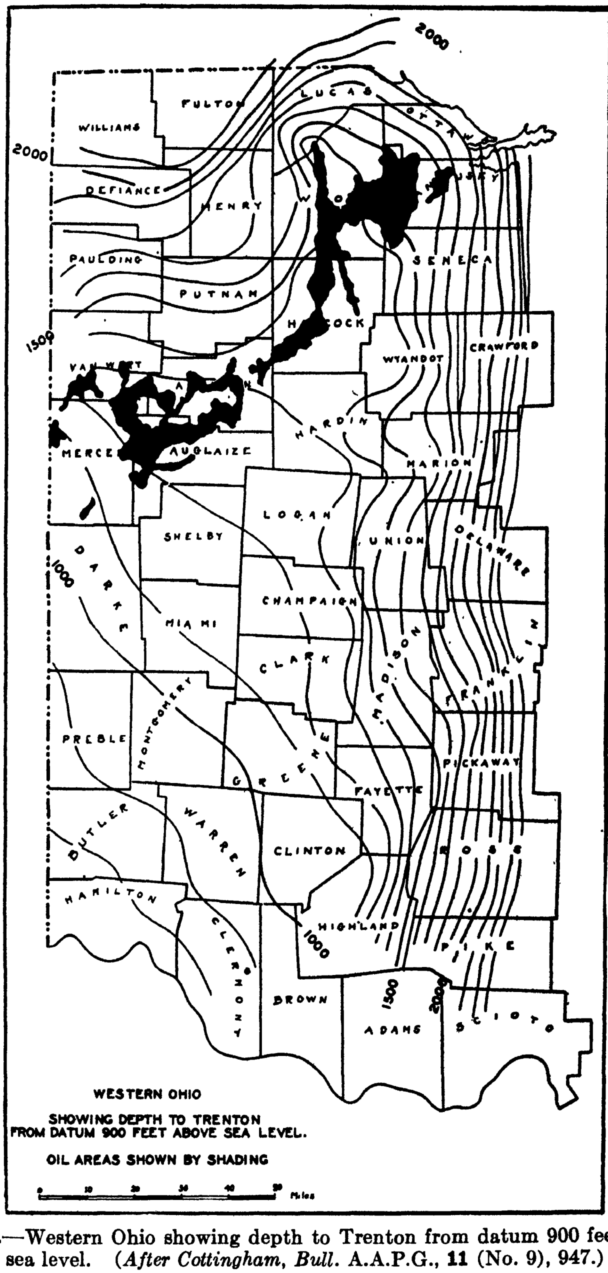

FIG. 37.—Western Ohio showing depth to Trenton from datum 900 feet above sea level. (*After Cottingham, Bull.* A.A.P.G., **11** (No. 9), 947.)

farther south where the arch is higher. In drilling wells, the drillers soon found that the good territory had what they called "crevices." These crevices sometimes were only 1 foot or less in depth, but sometimes the tools dropped 6 or 8 feet showing quite a hole or fracture zone. Orton explained those holes as being due to dolomitization of the limestone. Bownocker reports that fragments blown out by torpedoes sometimes show a honeycomb structure. Panyity[1] believes that the line of 25 per cent magnesium-carbonate content marks the limit of productive territory.

If more emphasis is placed on the statements of the drillers regarding the abundance of crevices and also on the fact that the largest oil and gas wells were secured where they reported numerous "crevices" then it might not be unreasonable to assume that solution of the Trenton when it was exposed to erosion has a great deal to do with the formation of the cavities. On this assumption, some irregularity of thickness should be found in the Trenton, but not necessarily, for in a limestone region where solution exceeds mechanical erosion, the surface of the formation may not be affected much, in which case the thickness of the formation would not vary. Still, on the former assumption of different thickness resulting from erosion (unconformity), we find interesting corroboration in the report of Bownocker.[2] He describes what the drillers call "the hog back" in Sec. 22 of Cass township. In the northeast quarter of the section, the Trenton lies at 1,040; in a well 400 feet east, it lies at 1,167—a drop of 127 feet; ¼ mile west of the first well the Trenton is found at 1,107—a drop of 67 feet; and one-fourth of a mile south of the same at 1,115—a drop of 75 feet. Still more suggestive is the report of the drillers that the limestone in the "hog back" is liable to cave and has many fissures.

Another piece of evidence which suggests this conclusion is the fact that some unusual structural features have been found in Indiana near Kentland. In this area, outcrops have been found[3] where the glacial drift is thin or absent. These outcrops reveal the Ordovician limestones standing at fairly high angles, up to 80 degrees.

[1] PANYITY, L. S., Oil- and gas-bearing horizons of the Ordovician in Ohio, *Bull.* A.A.P.G., 5 (No. 5), 615.

[2] *Ohio Geol. Survey Bull.* 1, p. 70, 1903.

[3] REEVES, JOHN R., The production of oil in Indiana, *Bull.* A.A.P.G., 9 (No. 2), 322; CHAMBERLIN, *Am. Jour. Sci.*, p. 217, September, 1923.

Stratigraphy.—The consolidated rocks of western Ohio are covered by glacial drift which varies greatly in thickness. Some preglacial channels were encountered in the drilling of wells which are over 200 feet deep. Below the drift in the area where production has been found, the drill passes through Monroe limestone as the first consolidated formation, or, where this is missing, through the Niagara limestone. As a matter of fact, the latter is much more common. In Sandusky County a well at Fremont passed through 160 feet of the Monroe formation and found the Niagara limestone below it 200 feet thick. Where complete, the Niagara formation shows the following sequence:

	Feet
White limestone	160
Blue limestone	20
White shale	2
Brown hard limestone	21
Grey shale	20

Below the Niagara limestone lies the Clinton limestone which has a thickness slightly in excess of 100 feet. It is succeeded below by the red shales of the Medina formation which average about 50 feet in thickness. The underlying Ordovician system is divided into the Cincinnati and Utica shales with the oil-bearing Trenton below. The shales are thick, the blue, soft shales of the Cincinnati formation reaching over 400 feet and the brown shales called the "Utica" over 250 feet. The Trenton limestone was found to be 729 feet thick in a well drilled at Findlay. Not many wells have penetrated the Trenton and the formations below the Trenton. In these wells, a considerable difference in the thickness of the Trenton is apparent. The minimum thickness shown is in the Dayton well (450 feet) and the maximum in the Mt. Vernon well (870 feet). This Trenton is probably the equivalent of the Galena of Illinois, and of the Black River, Lowville and Stones River of the southern Appalachian region.

The St. Peter in Ohio is a grey siliceous magnesian limestone. On solution it shows some quartz fragments, but it cannot be called a sandstone. In the Indiana part of the field, Phinney has described deep well cuttings which show considerable sand as well as the same siliceous limestone found in Ohio. At Findlay, the St. Peter siliceous limestone is 406 feet thick.

Below it there are 470 feet of Cambrian strata in the same well,before the pre-Cambrian is reached.

GENERALIZED STRATIGRAPHIC SECTION FOR WESTERN OHIO

System	Formation	Thickness, feet	Character
Glacial drift		40	
	Monroe	160	Grey magnesian limestone
Silurian	Niagara	200	Blue, white, and brown limestone with interbedded shales
	Clinton	100	Grey and red limestone
	Medina	50	Red shales
	Cincinnati	650	Blue shales with thin limestones
	UTICA		Brown shale in lower part
Ordovician	Trenton Lowville Stones River	730	Magnesian limestone
	St. Peter	406	Siliceous magnesian limestone
Cambrian		470	

Producing Horizons.—In western Ohio and eastern Indiana there are six possible oil horizons. The most important of these by far is the first porous zone in the Trenton formation. This zone seems to be located within the first 50 feet of the limestone, although it may occur almost anywhere within this thickness of rock. Rarely is oil or gas encountered at the very top of the formation. As a rule, there is an impervious tightly cemented zone of a few feet in thickness at the top which is called by the driller the "cap rock." Below the cap rock porous conditions set in which may be pronounced or only of moderate character or may be absent entirely. For that reason, there are many barren spots scattered through the productive area. Sometimes the oil and gas occur at nearly the same distance below the cap rock in adjacent wells, but sometimes such wells show abrupt difference in the position of the "pay zone." In the early development of the western Ohio fields, it was thought useless to attempt to find oil or gas below the 50-foot zone. Later, beginning about 1900, production was found at a second depth, and still later at a third depth in the Trenton. These two lower zones have not been very prolific. In Wood County the second pay was found at from 50 to 100 feet below the first pay zone. The third pay zone, if it may be called a zone, extends through

the remaining thickness of the rock. It has not proved to be of much value.

In addition to the great production coming from the Trenton, some wells have also found small production in higher and in lower formations. In Wood County, a good oil show is often found in the Clinton limestone. The Cincinnati shales below the Clinton sometimes produce considerable quantities of oil. Bownocker reports a well in Bloom township, Wood County, which came in for 300 barrels at a depth of about 300 feet in the Cincinnati shales. It produced about 5,000 barrels of oil and then stopped flowing. Another well near Waterville produced at the rate of 125 barrels a day from a similar horizon for a short time.

Another oil sand which possesses possibilities for the future but which up to date has not yielded any appreciable quantity of oil is the St. Peter horizon. The top of the "Magnesian limestone" (Calciferous of the eastern states; Beekmantown of Schuchert and Clarke, and Knox dolomite of the southern Appalachian states) is marked in western Ohio and especially in the Indiana extension of the field by the occurrence of true sand lenses and quartz-grain inclusions. They probably represent wind-blown sand deposited in shallow waters at the time the St. Peter sandstone was being accumulated farther north. At Findlay, seven wells are producing from the St. Peter horizon. They are all small, although one came in for 500 barrels per day. Porosity in this horizon is evidently very "spotted," for only one out of eight wells drilled in that vicinity came in as a producer. According to Panyity, these wells are located on the eastern flank of the Tiffin anticline on a nose and about 100 to 200 feet lower structurally. Farther east in central Ohio near Caledonia, in Marion County, four producers were drilled in, having an initial production of from 15 to 745 barrels.

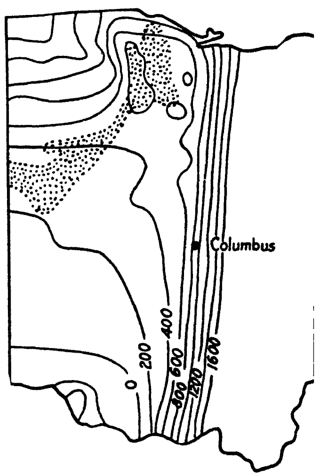

FIG. 38.—Sketch map of wester Ohio showing oil and gas fields an structure on top of St. Peter sandstone. (*After* Panyity, *Bull.* A.A.P.G., 5, 610.)

Other small producers were found in various parts of Ohio, but as a rule the wells encountered water at this level.

Relation of Production to Structure.—In the oil fields of western Ohio and eastern Indiana, the major tectonic element, the northward pitching Cincinnati arch, must be considered the chief factor in the accumulation of large quantities of gas, oil, and salt water. Subordinately, the difference in porosity of the Trenton limestone has produced the special localization of the oil and gas pools. This difference in porosity is partly due, no doubt, to dolomitization according to which a porosity, theoretically of as much as 12 per cent is possible, but more particularly to solution by ground water at a time when the Trenton was exposed to erosion. The dark-brown Utica shales appear to be the original source of the bituminous substances.

Production Statistics.—Some of the early wells drilled in Wood and Hancock counties came in for a daily production of from 5,000 to 10,000 barrels. These wells were very exceptional and always dropped rapidly in production. The smaller wells producing from 25 to 500 barrels were the remunerative wells, often lasting 10 to 12 years. Maximum production in Ohio was reached in the year 1896, when over 20,000,000 barrels were produced. In Indiana, maximum production reached the figure of 11,317,259 barrels in 1904. The total production to date from both areas is very close to 500,000,000 barrels. To secure this great amount of oil, over 60,000 wells were drilled. This oil has a density of 36 to 42° Bé., is chiefly of paraffin base, though some asphalt is present, and contains some sulphur.

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CUMBERLAND SADDLE DISTRICT

In Kentucky, the Cincinnati arch reaches a high point in Jessamine County near the village of Nicholasville very nearly in the center of the state and of the Blue Grass region. Here, the Trenton limestone of middle Ordovician age reaches the surface and covers a large area. Farther south, according to the cross-sections shown in Fig. 39, the Ordovician is overlain by the Devonian and Mississippian rocks. Of these two, the Devonian is very thin and the Silurian rocks are also very thin. In fact, the Silurian rocks are missing over the axis for a width of 30 miles. The Mississippian rocks cross the axis in considerable thickness and locally come to rest directly upon the Ordovician.

Between the two domes on the Cincinnati arch—the Nashville and the Cincinnati domes—there is a saddle or structural "low." It lies in southern Kentucky and seems to have its greatest depth in northern Cumberland and eastern Metcalf counties. This saddle becomes wider and deeper to the east and to the west. In the eastern part of the saddle lie the fields of Wayne and McCreary counties. In the western part of the saddle lie the fields of Allen, Barren, and Warren counties. Thus there are two groups of fields to be treated in this part of the chapter, both related to the Cumberland saddle and to the Cincinnati arch, but on opposite sides (see Fig. 32, p. 83).

Structural Elements.—The main controlling tectonic element is, of course, the axis of the arch which passes into the southern part of Kentucky with a strike about N. 20° E. Subordinately, the axis of the Cumberland saddle, which strikes almost at right angles to this direction through Warren, Barren, Metcalf, Cumberland, Russell, and Wayne counties, must receive consideration, and, finally, the dip given to the rock because of these major features is periodically interrupted by smaller local structures, as domes, small anticlines, terraces, and basins.

Stratigraphy.—In considering the stratigraphy of the fields of southern Kentucky some difficulties are encountered in nomenclature. Systematic studies of the rock succession in areas close to this part of the country were carried on from different directions. The typical formations were named and first

described at points far removed both to the east and to the west. In this small area is found the merging of names and perhaps the merging of formations traced from the Appalachian Mountains on the east and the Mississippi River sections on the west. The greatest similarity to the nomenclature used in this book is found on the eastern side of the axis, in Wayne and McCreary counties. Below is given a section based on Munn's work in these counties:

GENERALIZED SECTION OF ROCKS FOR WAYNE AND MCCREARY COUNTIES

System	Formation	Thickness, feet	Character
Pennsylvanian	Lee (Pottsville)	0 to 400	Coarse, brown, massive conglomerate and sandstone at top, the *Rockcastle* member. Alternating beds of sandstone and shale below with occasional thin coals
	Pennington (Mauch Chunk)	0 to 250	Red and green shale with thin limestone beds. Spann limestone near base
Mississippian	Newman (Greenbrier)	462	Blue and grey limestone with a persistent sandstone about 100 feet below top and a cherty, calcitic porous limestone near base called "stray" oil sand
	Waverly 2½ m/b.	270	Upper 150 feet consists of compact, blue shale. Lower part consists of soft green shales with cherty, geodic siliceous limestone. The cherty limestone in the lower portion of this part is the "Beaver Creek" oil sand
Devonian	Chattanooga	25	Black shale
Silurian	Osgood	14	Green shale and limestone
	Clinton	19	Limestone
Ordovician	Cincinnatian	1,500	Blue shale and interbedded limestones
	Trenton		Grey crystalline limestone, with some chert especially toward the base. Includes Hermitage
	Black River		Dense fine-grained massive limestone
	Stones River		Grey and dove-colored, dense limestone
	St. Peter		Siliceous limestone

The *Pottsville* formation, called the "Lee formation" in this part of Kentucky, has very little interest for the oil geologist. It consists of sandstones, conglomerates, and thin shales and coals. The coals cannot be used for surface mapping because of the great erosion interval between the Pennsylvanian and the Mississippian. The *Mauch Chunk* formation, here called the "Pennington," shows this erosion interval by its great difference in thickness from place to place. It seems to be thickest in the southern part of Wayne County where it has a thickness of 250 feet. To the north and northwest, it thins out often to a feather edge. Its probable equivalent on the other side of the Cincinnati arch is the Birdsville member of the Chester formation. It contains a limestone near the base which may be used as a key horizon for surface mapping, the Spann limestone.

Below the Pennington lies the massive limestone which corresponds to the Greenbrier with which we became familiar in West Virginia and western Pennsylvania. It is from 450 to 550 feet thick. A very persistent sandstone occurs near the top of the formation. This may be the "tan sand lens" found in the Big Lime farther east and north in Kentucky. A portion of the *Newman limestone* is equivalent to the St. Genevieve limestone. Above this portion lies a sandstone which may be the same as the Hartselle sandstone, with which we shall have to deal in Alabama and Mississippi. This, in turn, may be correlated with the Cypress sandstone, which will be considered later when dealing with the fields of the Eastern Interior Coal Basin Province. The portion lying above the sandstone is equivalent to the lower part of the Chester of western Kentucky.

The *Waverly* formation of the Mississippian system is the most important part of the section in this part of the state, for it contains the only "oil sand" worth mentioning. It varies in thickness from 150 to 260 feet and consists of shales with a few limestones. On the other side of the Cincinnati axis, it corresponds to the New Providence formation.

The black shale called "Chattanooga" is the most important key rock for subsurface correlation. It is not very thick in these counties, ranging from 10 to 40 feet and, in fact, it is missing in the western part of Wayne County so that the Mississippian rocks rest directly upon the Ordovician rocks. The Silurian rocks also are very thin or missing in the area under discussion. About 14 feet of the Osgood shale and 19 feet of the Clinton limestone

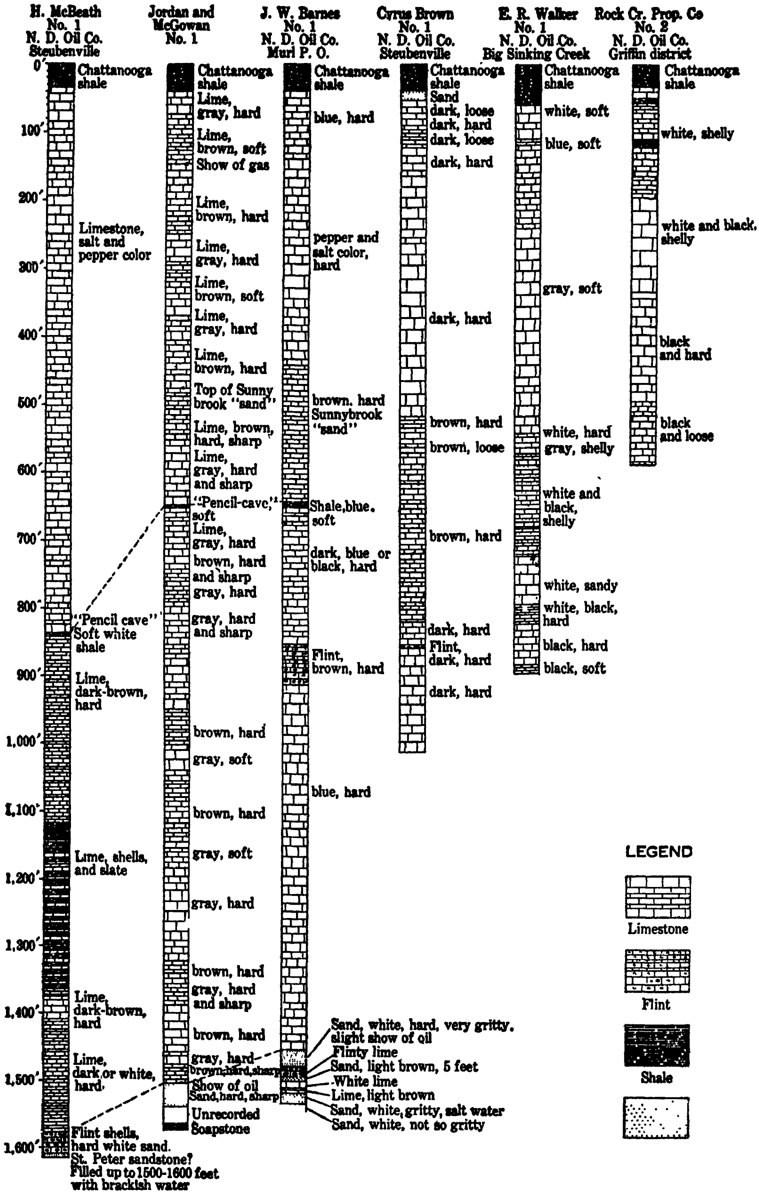

FIG. 39.—Sections of deep wells in Wayne County, Kentucky, showing character of rocks below the Chattanooga shale as reported in logs by drillers. (*After Munn, U. S. Geol. Survey Bull.* 579, 16.)

were described from an exposure at the mouth of Little Cub Creek in Wayne County by Foerste. West of this outcrop, the Silurian thins very rapidly and disappears entirely from the section.

The Cincinnati shale series, subdivided farther north into the Richmond, Maysville, and Eden, is probably represented by some of the limestones found just below the black shale in the well records. The Trenton, Black River, and Stones River limestones cannot be separated in the well logs and are, therefore, thrown together in the generalized section. At least three deep wells in Wayne County have penetrated this succession and found a hard, white sandstone below. Whether this is the *St. Peter* or not is a question. It may be a Cambrian sandstone, because the St. Peter horizon is more likely represented by a portion of the magnesian limestones and is not a true sandstone. The interval between the black shale and the sandstone horizon varies from 1,470 to 1,600 feet. An interesting horizon because of its possibilities for subsurface correlation is a thin zone of a few feet thickness called in the well records "pencil cave." This is a bed of *bentonite*, or volcanic ash, which has been found to be very widespread in Tennessee and Kentucky. It lies about 10 feet below the base of the Trenton formation in the upper part of the Black River formation (Carters member of Tennessee). It may be described as a green, sticky clay with occasional mica flakes.

Producing Horizons.—Only one stratigraphic horizon has been found very productive in the area under discussion. This is the Beaver Creek sand, so named because it was first found in wells drilled along Beaver Creek. It is a limestone which is very cherty and contains many geodes, which may account for its porosity. It is generally referred to the Chattanooga shale in position, but, because of the considerable unconformity at the base of the Mississippian, this interval varies greatly. As a rule, it is found within a few feet of the black shale, but may be as high as 60 feet above it. It is also possible that the name is incorrectly used by drillers in connection with any limestone near the base of the Waverly that has a show of oil in it.

The Sunnybrook Sand.—In the extreme southwestern part of Wayne County is the town of Sunnybrook. A well drilled on a farm near by found oil at a depth of 550 feet below the Chattanooga, in 1901. This horizon was therefore called the "Sunny-

brook sand." According to Nelson,[1] this horizon is at the base of the Hermitage member of the Trenton formation. In the Celina oil fields, described by Lusk,[2] two Sunnybrook sands

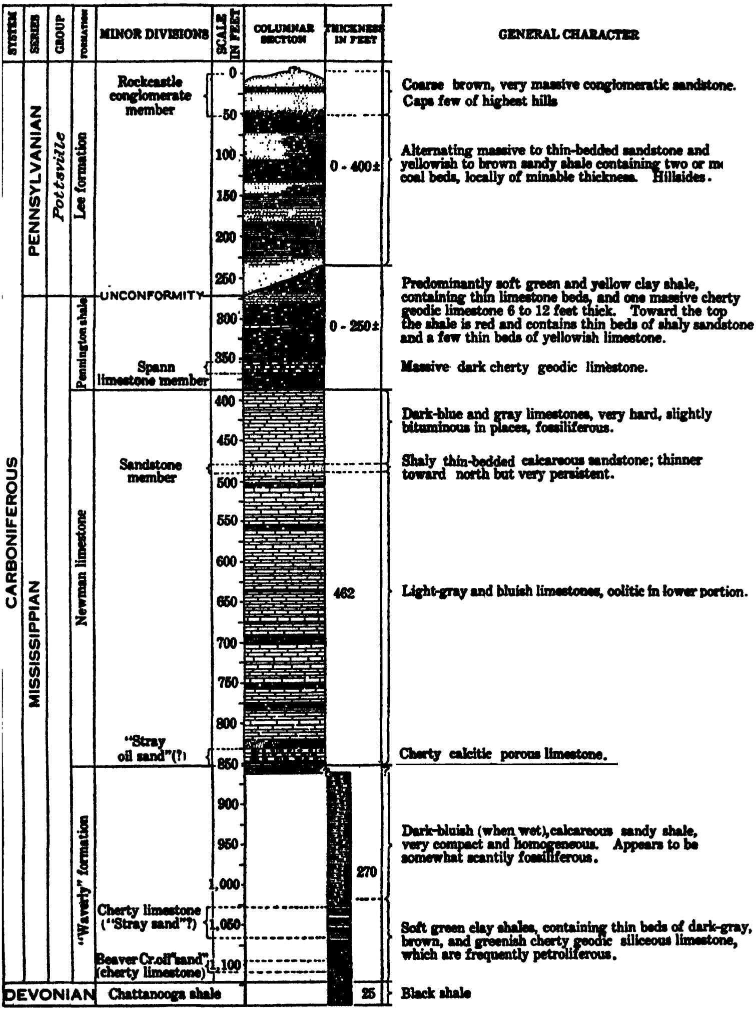

FIG. 40.—Generalized section of rocks exposed in Wayne County, Kentucky. (*After Munn, U. S. Geol. Survey Bull.* 579.)

[1] NELSON, W. A., Oil development along the Tennessee-Kentucky line during 1923, *Bull.* A.A.P.G., **8** (No. 4), 454–458, 1924.

[2] LUSK, R. G., The significance of structure in the accumulation of oil in Tennessee, *Bull.* A.A.P.G., **11** (No. 9), 905 *ff.*, 1927.

are differentiated. The one here described is the second or lower Sunnybrook. The upper Sunnybrook horizon is in the Cannon member of the Trenton about 235 feet below the Chattanooga shale. Some of the wells drilled into this sand produced from 100 to 200 barrels per day. As usual with limestone wells, however, the production was short lived.

Relation of Structure to Production.—In the three most important fields of these counties, Munn found that there is a certain structural relationship between the productive zones and the attitude of the rocks. He found that there is a tendency for the oil to occupy the sides and bottoms of structural troughs; that there is a definite decrease in altitude of the sand in the productive areas from west to east in each district; and that the pools in the Beaver Creek sand appear at approximately the same altitude.

The oil from the various fields in Wayne and McCreary counties varies greatly in gravity. Oil from the Rocky Branch pool is black and has a gravity of 25.2°. The oil from the Johnson Fork field is brown and has a density of 36° Bé. The highest gravity is shown by the light-green oil from the Parnell pool and comes from the Sunnybrook sand.

Oil Pools on the Western Side of the Arch.—No oil or gas has been found on the axis of the arch in Kentucky. On the west flank of the arch, oil is produced in considerable quantities in Allen, Warren, and Barren counties. This is another region where oil springs and gas seepages played a part in starting drilling activity. One of the large and well-known springs is located on Drake's Creek, a branch of Barren River, a few miles southwest of Scottsville. Some of this oil collected by means of a blanket, according to the Indian custom, had been sent to Pittsburg before 1850 to be sold as medicine. Another oil spring was known on Little Trammel Creek near the settlement of Petroleum Station. The first well was drilled in 1866. The location was a fortunate one, considerable oil was found, but, because of the high sulphur content of the crude, it did not meet the refiner's standards and interest in drilling died down. The real drilling campaign began in 1887, after the western oil fields of Ohio had aroused interest in the Trenton rock and its oil.

Tectonic Elements.—The controlling tectonic element in the western half of the south-central part of Kentucky is the Cin-

cinnati arch whose axis passes about 30 miles east of the oil fields through Cumberland County. Subordinately, they lie in a synclinal trough which trends nearly east and west in southern Kentucky and produces a saddle in the major structural element. This saddle pitches toward the west and northwest, finally merging with the basin of the Central Interior coal basin. The normal regional dip therefore is north and northwest as the fields are located on the southern flank of the saddle.

The minor structural features which are impressed upon the regional dip consist of a few small domes which show a strong tendency to be elongated parallel to the strike of the strata. Five such domes are shown on the map of a part of Allen County, prepared by Shaw and Mather.[1] These domes are about 2 miles or less along the major axis and nearly a mile wide across the minor axis.

Stratigraphy.—The rocks which crop out on the surface on the west flank of the Cincinnati arch in southern Kentucky belong to the Mississippian system. They are not the typical Mississippian rocks, however, with which we have become acquainted in Ohio, Pennsylvania, West Virginia, and eastern Kentucky. In those regions, this system is made up typically of three divisions—a shale zone below and above and a massive limestone zone in the middle. The clastic zone at the base is usually called the "Waverly," and is predominantly shale with a little sandstone. This zone in Tennessee is made up chiefly of cherty limestone called the *Tullahoma* and *Ft. Payne,* while in the area to the west, in the upper Mississippi basin, rocks of approximately the same age consist of fossiliferous limestone and shale called Kinderhook, Burlington, Keokuk, and Warsaw. This is a region where the shales and thin sandstones of the east and the cherty limestones of the south merge and form a transition facies toward the fossiliferous limestones and shales of the area to the north and west.

The Waverlian rocks in this part of Kentucky are divided into three divisions: the New Providence shale, the Ft. Payne chert, and the Warsaw limestone. The lowest of these, the *New Providence,* consists of 40 to 50 feet of shale and shaly limestone with a predominant bluish-green tinge. It varies from place to place, occasionally showing very massive limestone beds or calcareous beds composed largely of crinoid stems, loosely

[1] *U. S. Geol. Survey Bull.* 688, Pl. II.

The Devonian *black shale* is a very important key horizon in this part of the state as it is elsewhere. It is not very thick but is always recognized by the driller. In this region, some of it is brown and at places thin black limestones are included in it. The underlying limestone has been called the "Boyle limestone," by Foerste. It is the Corniferous limestone so prolific on the eastern side of the Cincinnati arch. It crops out in the eastern part of Allen County and has many cavities and solution holes in it. At some points, it presents a decidedly sandy facies and after prolonged solution has a gritty surface because the quartz particles weather out in relief. In the well records, it is not possible to separate this limestone from the Silurian limestone below it.

The Silurian *Niagara limestone* begins to come into the section in Allen County (Fig. 41). Farther east it is not present,

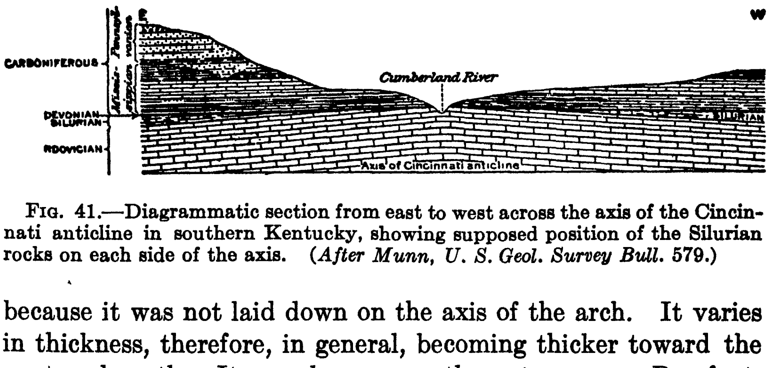

FIG. 41.—Diagrammatic section from east to west across the axis of the Cincinnati anticline in southern Kentucky, showing supposed position of the Silurian rocks on each side of the axis. (*After Munn, U. S. Geol. Survey Bull.* 579.)

because it was not laid down on the axis of the arch. It varies in thickness, therefore, in general, becoming thicker toward the west and north. It may be seen on the outcrop near Barefoot, Tennessee in the extreme southern part of Allen County. Here, the upper portion of the limestone contains so much quartz sand that it can be called a "calcareous sandstone." Also, in the lower 90 feet there are a great many sandy layers. It thus becomes a possible reservoir rock for oil and gas.

Below the Silurian limestones occur "slate and shells" in the average driller's record. These are, no doubt, to be correlated with the members of the Cincinnatian series farther north. They appear to be about 650 feet thick. Below these shaly layers, the massive limestones set in and continue down to the lowest depth any well has penetrated. In the J. W. Cook well, a water-bearing layer was found at a depth of 3,142 feet which may be the *St. Peter* horizon. The thick limestones above this horizon

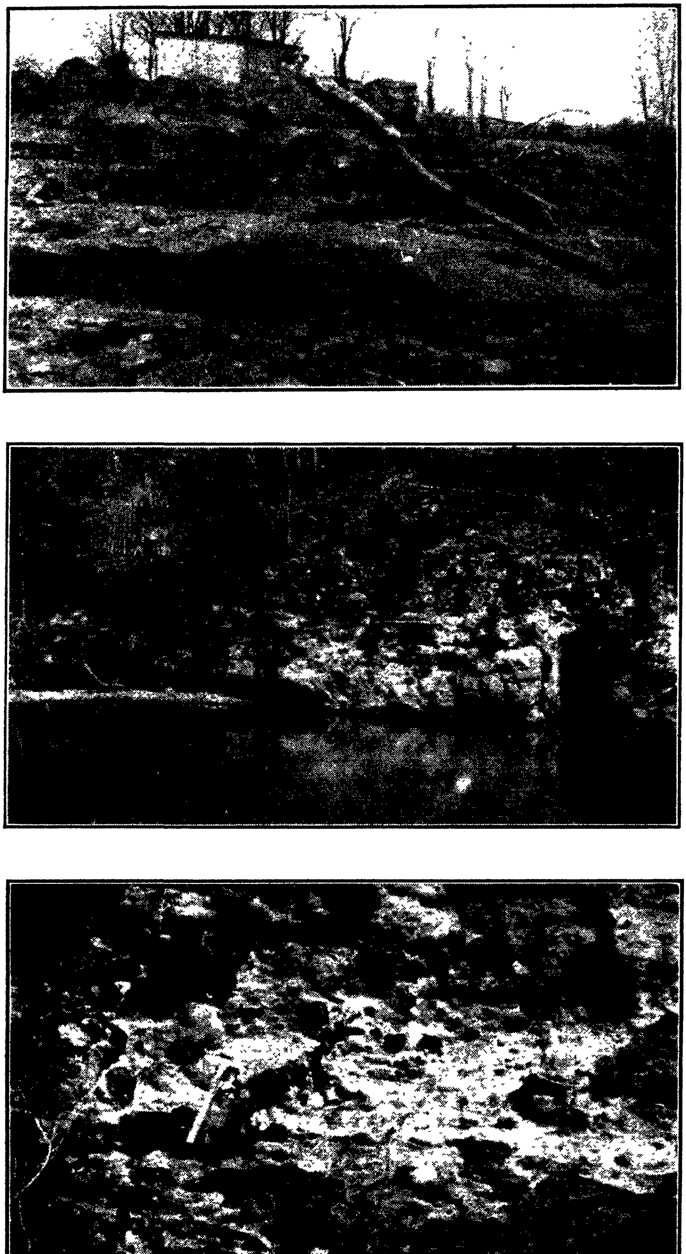

FIG. 42.—Exposures of Corniferous limestone, the oil sand of many Kentucky oil fields. (*After Shaw and Mather, U. S. Geol. Survey Bull.* 688.)

from the top of the Trenton measured 980 feet. These limestones, according to the generalized section of Ulrich for the rocks of the Cincinnati dome, probably include the Black River, Blount, and Stones River, as well as the Trenton.

Producing Horizons.—In this part of Kentucky, oil has been found in eight or nine different horizons, six of which have proved of commercial importance. These horizons are as follows: St. Louis, Corniferous, and Niagara limestones, and the Beaver sand in the New Providence formation.

Near the base of the St. Louis formation is a dark crystalline limestone which is porous locally and contains gas, oil, and salt water. It accounts for some of the gushers found near Bowling Green which obtained their oil in the basal 20 or 30 feet of the limestone. St. Clair[1] believes that this horizon, where productive, may occupy shallow erosional depressions in the underlying formation, or sinkholes. Some wells in this horizon came in for 2,000 barrels per day, but, as usual with limestone wells, soon exhausted themselves. Some wells starting as salt-water wells after pumping a few days came in to oil. St. Clair also reports that a well pumping salt water down the dip from another may draw oil from the latter, indicating that each pool, or rather unit of a pool, is an isolated body containing a limited amount of fluids which can be exhausted. He believes, therefore, that the oil and gas have not migrated far.

The *Beaver sand* is found in the upper part of the New Providence shale, and is not to be confused with the Beaver Creek sand of eastern Kentucky. It produces only in the eastern part of Warren County. Some wells in this sand came in for 100 barrels or better but the total production of the area in which this sand produces is small. In the Corniferous limestone, considerable production is found. In Warren County, there are two pay zones in this rock. The upper pay zone lies from 2 to 10 feet below the Chattanooga shale and is from 5 to 10 feet thick. It is the more important of the two. Some of the early wells in the Moulder and Sledge pools came in for 1,000 barrels per day from this horizon. Both gas and salt water occur with the oil and the pressure declines rapidly. In Allen County, this horizon is also important. There the position of the oil- and gas-bearing horizon in the limestone varies a great

[1] St. Clair, Stuart, Oil geology of Warren County, Kentucky, *Bull. A.A.P.G.*, **6** (No. 1), 28, 1922.

deal and apparently may occur at any depth. In one field, it occurs below a "cap rock" 3 to 12 feet thick, and the porous zone is 15 feet thick. The pay streaks in the Corniferous (see Fig. 42) seem to differ from the rest of the rock in being softer and less indurated besides showing greater porosity. It is altogether likely that this condition is due to solution during Devonian time when the rock was exposed to weathering for a short time before the deposition of the black shale.

The *Niagara limestone* is the most important producing formation in this part of the state. In Warren County, it produces only in the west-central part of the county. Here, the pay zone lies from 68 to 130 feet below the black shale. Where it produces, the limestone is soft, earthy, and contains very little sand. In Allen County, the pay zone is found at depths of from 50 to 130 feet below the Chattanooga shale. It does not seem to have the large openings which characterize the Corniferous, but instead has many small pores, probably due to its sand content. At some places in Allen County there are two or three pay zones in the Niagara. The thickness of the pay zones varies from a fraction of 1 foot to 17 feet.

Relation of Production to Structure.—A careful study of the maps which have been published, showing the structure of this part of the oil fields of Kentucky, shows a more faithful relation to structure than we have been able to report elsewhere. Quite a number of pools are located on small domes and elongated anticlines. On the other hand, some similarly favorable locations have furnished only dry holes, and again some good pools are located in synclines. The conclusion, therefore, is that differential porosity has a controlling influence (see Fig. 42). In Warren County, St. Clair reports that most of the producing wells in the Niagara are located on the tops, or high on the flanks, of anticlines or domes. The oil in the Beaver sand, however, is controlled entirely by porosity conditions and structure is subordinate. The oil in the basal St. Louis is quite independant of structure.

As to origin and accumulation of the oil, the most logical conclusion is that the oil originated in the Chattanooga for the most part and migrated, laterally, upward and downward to its present position. Some of the oil in Warren County may have originated in shales closer to the producing horizons. This seems to be especially true of the oil in the basal part of the St. Louis limestone.

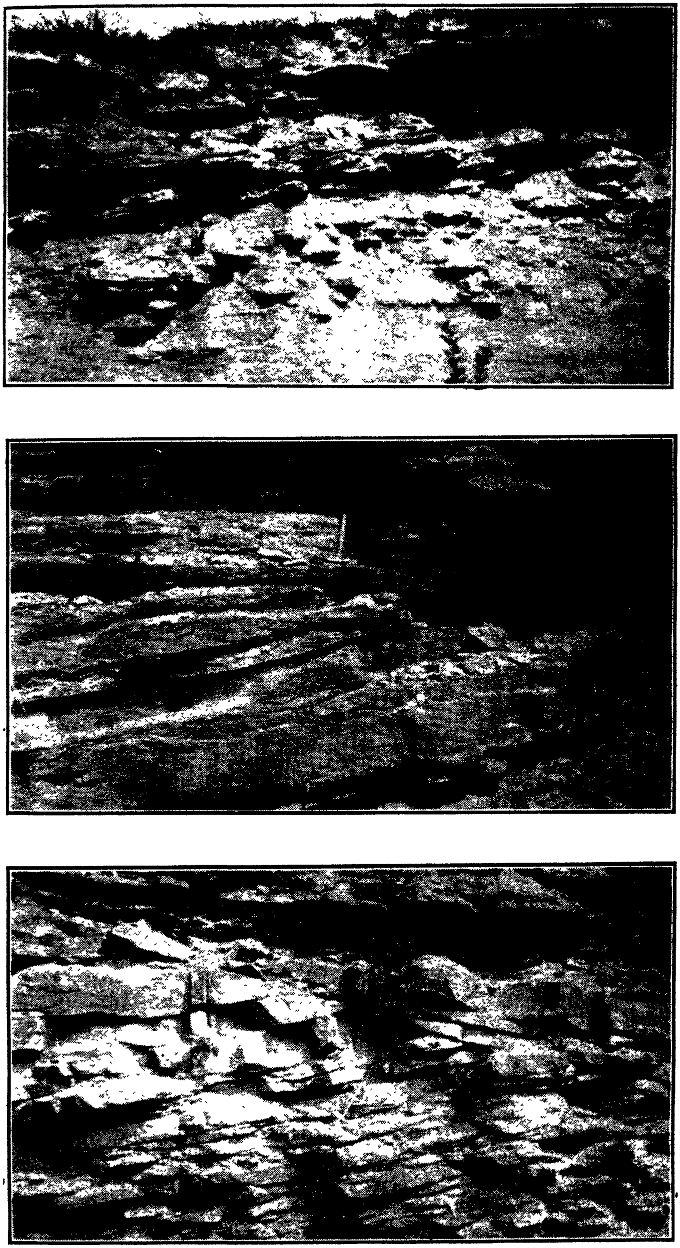

FIG. 43.—Original structural features of little or no value in oil and gas finding, exposed in railway cut 1 mile south of Petroleum, Kentucky. (*After Shaw and Mather, U. S. Geol. Survey Bull.* 688.)

The oil derived from the Corniferous and the Niagara formations is dark green in color and has a density ranging from 23 to 33° Bé.

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TENNESSEE

Very little oil or gas has been produced in the state of Tennessee and the prospects of finding more appear to be decidedly limited. Nevertheless, some oil has been found and it is interesting to note how its occurrence compares to that of other parts of the country. All the oil fields are located in the north-central portion of the state and on the eastern flank of the Cincinnati arch. They form a natural continuation of the oil fields of Wayne and McCreary counties in Kentucky. Pickett, Fentress, and Overton counties lie in this part of the state, and it was in these counties that the earliest wells were drilled shortly after the Civil War. Poor results led to a cessation of drilling which was, however, revived in 1892 when the Spurrier district in Pickett County was opened and was followed by the discovery of oil at Riverton in the same county. The oil was soon exhausted from these areas and no further production was found until 1915. In that year, oil was found near Oneida in Scott County, which lies east of Fentress County. This field also failed in a short time. In 1916, oil was found at Glen Mary in the same county, and this pool seems to have had better success than its predecessors. The early wells came in for 6 to 8 barrels, mostly, although one gusher came in for 350 barrels. Four years later, this pool was still producing 1,000 barrels per month. Still later, fairly good production was found at Tinsley's Bottom in Clay County and near Spring Creek in the southern part of Overton County. In 1926, oil was found near Celina in Clay County.

Areal Geology and Stratigraphy.—The map (Fig. 44) shows that Tennessee is built up of Paleozoic rocks in the eastern part, Ordovician rocks in the central basin area, and Mesozoic and Cenozoic rocks in the western part. Around the central Nashville basin (topographic) is a "rim" of Devonian and Mississippian rocks. All the important oil pools are located in the rim area and west of the Pennsylvanian outcrop belt.

The rocks on the surface are of Mississippian age. In places the *Pennington shale* forms the rock mantle, but it is thin or missing over large areas. The next formation is the *St. Louis*

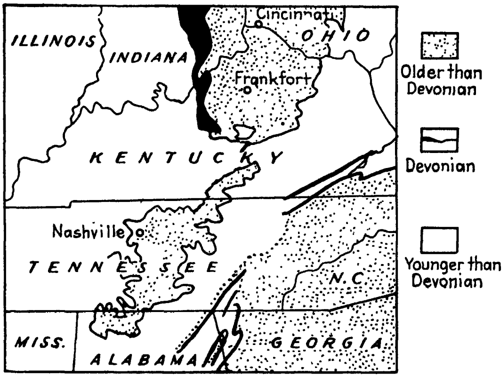

FIG. 44.—Geologic sketch map of Kentucky, Tennessee and parts of adjoining states showing the area underlain by Devonian strata. (*After Shaw and Mather, U. S. Geol. Survey Bull.* 688.)

limestone. It is a bluish, massive limestone of fine texture. The underlying Warsaw contains some limestone but also contains much shale and some sandy layers. The *Ft. Payne* and *New Providence* formations include clastic materials of all kinds and are very variable in their horizontal extent. The most characteristic portions are the coarse crystalline limestones with geodes and the prominent chert lenses. The oil horizons at Spring Creek and Bone Camp appear to lie within the New Providence. The black shale so characteristic in all the oil areas of the Appalachian province is present here, but very thin. It ranges from 15 to 150 feet, thickening to the east and north As usual, it is the most useful key bed for underground correlation purposes.

A great unconformity appears in the section below the Chattanooga. This unconformity eliminates all rocks of Devonian

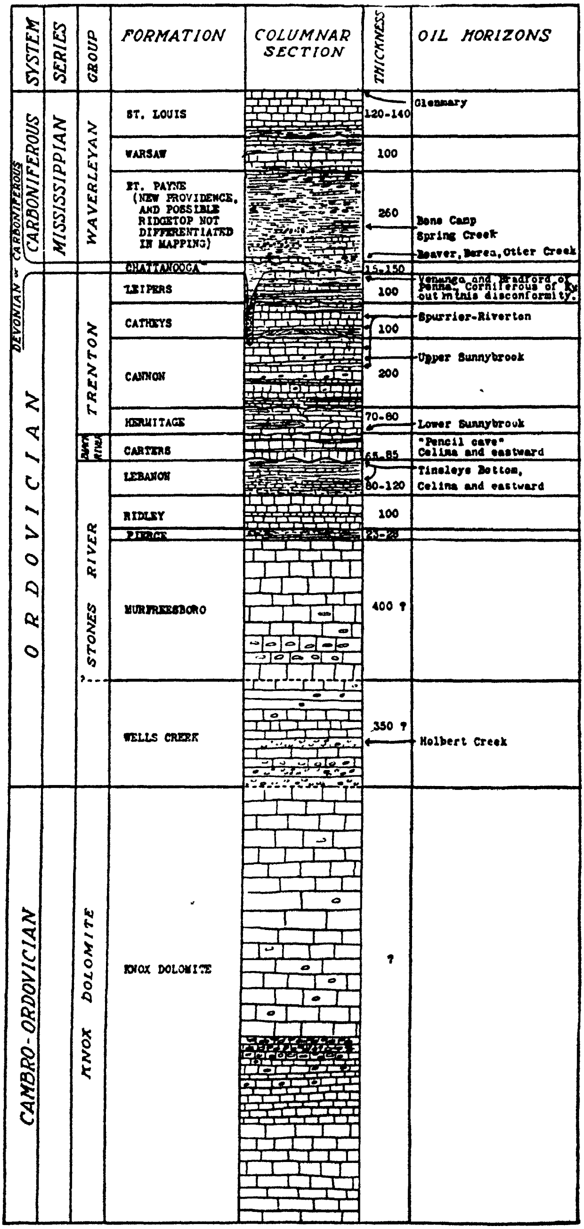

FIG. 45.—Generalized columnar section for northeast middle Tennessee. (*After Lusk, Bull.* A.A.P.G., **11**, 908.)

as well as all of Silurian age and a good deal of the upper Ordovician. The youngest Ordovician rocks bear the name "Leipers" and are thought to be of Trenton age. They are thin-bedded limestones with some shaly layers. The next lower formation or member of the Trenton is the Catheys, which is similar lithologically to the Leipers. It contains several oil horizons. The Cannon member of the Trenton is more typical, consisting of massive limestone. It is 200 feet thick and contains the upper Sunnybrook oil zone. The Hermitage member of the Trenton, which is also limestone, contains the lower Sunnybrook at the base. The Black River is represented by the Carters member which is important because it contains the "pencil cave," which is a name given to a soft greenish shaly streak because it breaks up into fragments that are pencil-like in shape. It is a zone which has been traced over many square miles of territory and appears to be an ancient bed of volcanic ash or *bentonite.* For subsurface mapping, it is second only to the Chattanooga shale in value.

Below the Black River are other limestones of Ordovician age which, however, are of little importance to the oil geologist. The Stones River is represented by four or possibly five members down to and including the Wells Creek (see Fig. 45). Below the Wells Creek lies the very thick Knox dolomite of Cambro-Ordovician age.

Producing Horizons.—There are at least five well-defined horizons in the stratigraphic section which produce oil at some place or other in the Tennessee oil fields on the eastern side of the arch. The oldest one in this area, and possibly the oldest in the United States, is in the Knox dolomite at a depth of 800 feet below the Pencil Cave horizon. The Holbert Creek well in the eastern part of Pickett County produced oil from a zone 65 feet thick in this horizon. Lusk[1] is inclined to place this horizon somewhat higher up in the lower portion of the Stones River. In the Tinsley's Bottom field and near Celina in Clay County, production is found in the uppermost portion of the Stones River at the contact between the Carters and Lebanon limestones and within the Lebanon limestone about 50 to 100 feet below the *pencil cave.* The next horizons, going up in the section, are the two Sunnybrook zones first found in Wayne County, Kentucky. The lower Sunnybrook is placed at the

[1] See Bibliography.

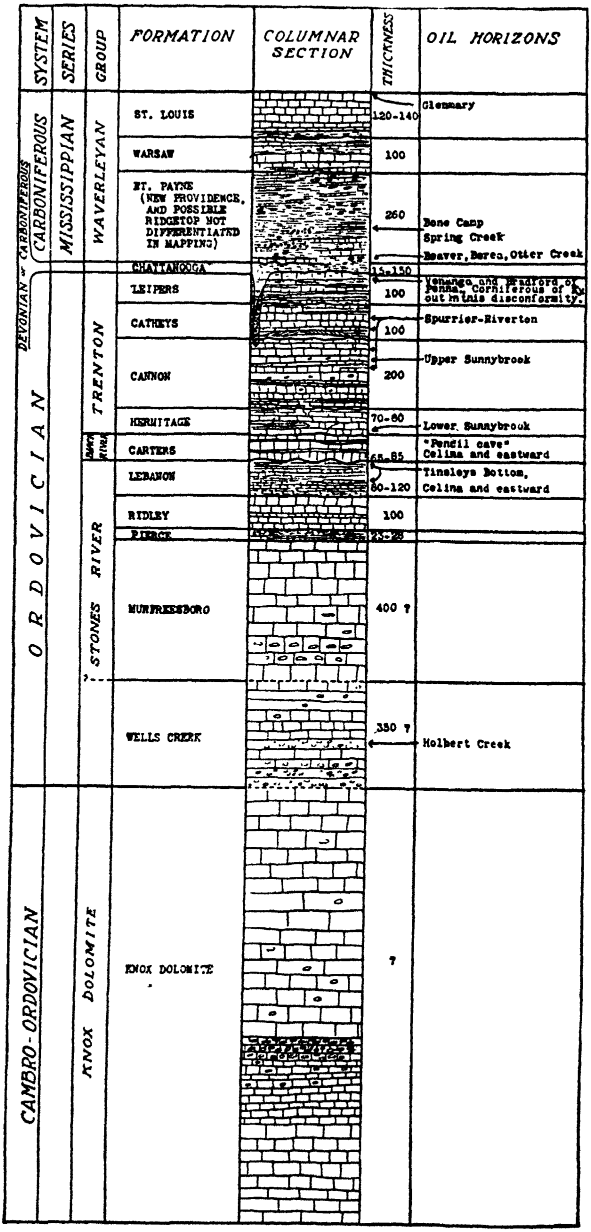

FIG. 45.—Generalized columnar section for northeast middle Tennessee. (*After Lusk, Bull.* A.A.P.G., **11**, 908.)

as well as all of Silurian age and a good deal of the upper Ordovician. The youngest Ordovician rocks bear the name "Leipers" and are thought to be of Trenton age. They are thin-bedded limestones with some shaly layers. The next lower formation or member of the Trenton is the Catheys, which is similar lithologically to the Leipers. It contains several oil horizons. The Cannon member of the Trenton is more typical, consisting of massive limestone. It is 200 feet thick and contains the upper Sunnybrook oil zone. The Hermitage member of the Trenton, which is also limestone, contains the lower Sunnybrook at the base. The Black River is represented by the Carters member which is important because it contains the "pencil cave," which is a name given to a soft greenish shaly streak because it breaks up into fragments that are pencil-like in shape. It is a zone which has been traced over many square miles of territory and appears to be an ancient bed of volcanic ash or *bentonite*. For subsurface mapping, it is second only to the Chattanooga shale in value.

Below the Black River are other limestones of Ordovician age which, however, are of little importance to the oil geologist. The Stones River is represented by four or possibly five members down to and including the Wells Creek (see Fig. 45). Below the Wells Creek lies the very thick Knox dolomite of Cambro-Ordovician age.

Producing Horizons.—There are at least five well-defined horizons in the stratigraphic section which produce oil at some place or other in the Tennessee oil fields on the eastern side of the arch. The oldest one in this area, and possibly the oldest in the United States, is in the Knox dolomite at a depth of 800 feet below the Pencil Cave horizon. The Holbert Creek well in the eastern part of Pickett County produced oil from a zone 65 feet thick in this horizon. Lusk[1] is inclined to place this horizon somewhat higher up in the lower portion of the Stones River. In the Tinsley's Bottom field and near Celina in Clay County, production is found in the uppermost portion of the Stones River at the contact between the Carters and Lebanon limestones and within the Lebanon limestone about 50 to 100 feet below the *pencil cave*. The next horizons, going up in the section, are the two Sunnybrook zones first found in Wayne County, Kentucky. The lower Sunnybrook is placed at the

[1] See Bibliography.

base of the Trenton by Lusk and the upper Sunnybrook in the Cannon member of the Trenton. Both of these horizons account for some of the production near Celina in Clay County.

The Cannon limestone also produces some oil in the older Spurrier and Riverton areas in Pickett County. In this district, there are at least 13 different porous zones which yield some oil within 508 feet below the Chattanooga shale. This district produced a total of 80,000 barrels of oil between 1892 and 1906.

The Mississippian horizons which produce oil are the Ft. Payne and St. Louis formations. In the Spring Creek field in southern Overton County, oil is obtained in small quantities from the Ft. Payne strata. Only 7,000 barrels of oil were taken from this area where it occurs in crevices in the rock. The first well was drilled in 1866 near a small oil seepage and at 52 feet struck a large flow of oil, most of which was lost because it was unexpected. In the Bone Camp field in Scott County, oil is found at a depth of 1,400 feet in the middle of the Ft. Payne formation 75 to 100 feet above the Chattanooga shale.

Finally, the top of the middle Mississippian limestone, called here the "St. Louis limestone," produces some oil at Glen Mary 4 miles northeast of the Bone Camp field. About 25 wells have been drilled in this field and something like 10,000 barrels of oil have been marketed.

On the western flank of the Cincinnati arch, one field has been opened which may have bright prospects. This is the Adolphus field in Sumner County which is located just south of Allen and Simpson counties in Kentucky and this area should show great similarity to the fields described from the adjacent part of Kentucky. Production in this field is probably from the Niagara limestone as it is found at depths of less than 100 feet below the Chattanooga.

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ALABAMA AND MISSISSIPPI

The first well in Alabama was drilled in 1909, and came in late in December of that year as a gasser at a depth of 1,400 feet. The amount of gas was sufficient (1,500,000 cubic feet per day) to encourage further drilling with the result that a number of other wells were drilled in the same vicinity, some of which were commercial producers. The locality where these wells were drilled is 2 miles east of the town of Fayette in the county by the same name which lies in the west-central part of the state (see Fig. 46). As the map shows, the outcropping rocks are of Cretaceous age, but rocks of Pennsylvanian age appear in the deeper stream cuts and may be studied there with a view to ascertaining the structure of the area. Inasmuch as the Cretaceous rocks were laid down after a long period of erosion, they do not reflect the structure of the older Paleozoic strata. Munn showed[1] that the Fayette gas sand was one of the sands in the Pottsville formation.

Below the Pottsville, there is a major unconformity in this region which may eliminate the upper Mississippian strata so that the middle Mississippian limestone, here called "Bangor limestone," may be expected under the Pottsville. Under the Bangor limestone series lies the Oxmoor sandstone (more commonly called the "Hartselle sandstone" in northwestern Alabama). This sandstone is looked upon with very great favor because of the frequent appearance of asphalt, which often composes as much as 12 per cent of the rock mass on the outcrop. It appears that it might carry considerable quantities of oil if it could be found under favorable cover and structural conditions.

A number of deep wells penetrated this horizon and reached well into the lower Ordovician strata in northwestern Alabama and adjacent parts of Tennessee and Mississippi. These wells are discussed in an article by Bramlette in *Bulletin* 781 of the U. S. Geological Survey.

[1] Munn, M. J., The Fayette gas field, Alabama, *Bull. U. S. Geol. Survey* 471, p. 30–55, 1912.

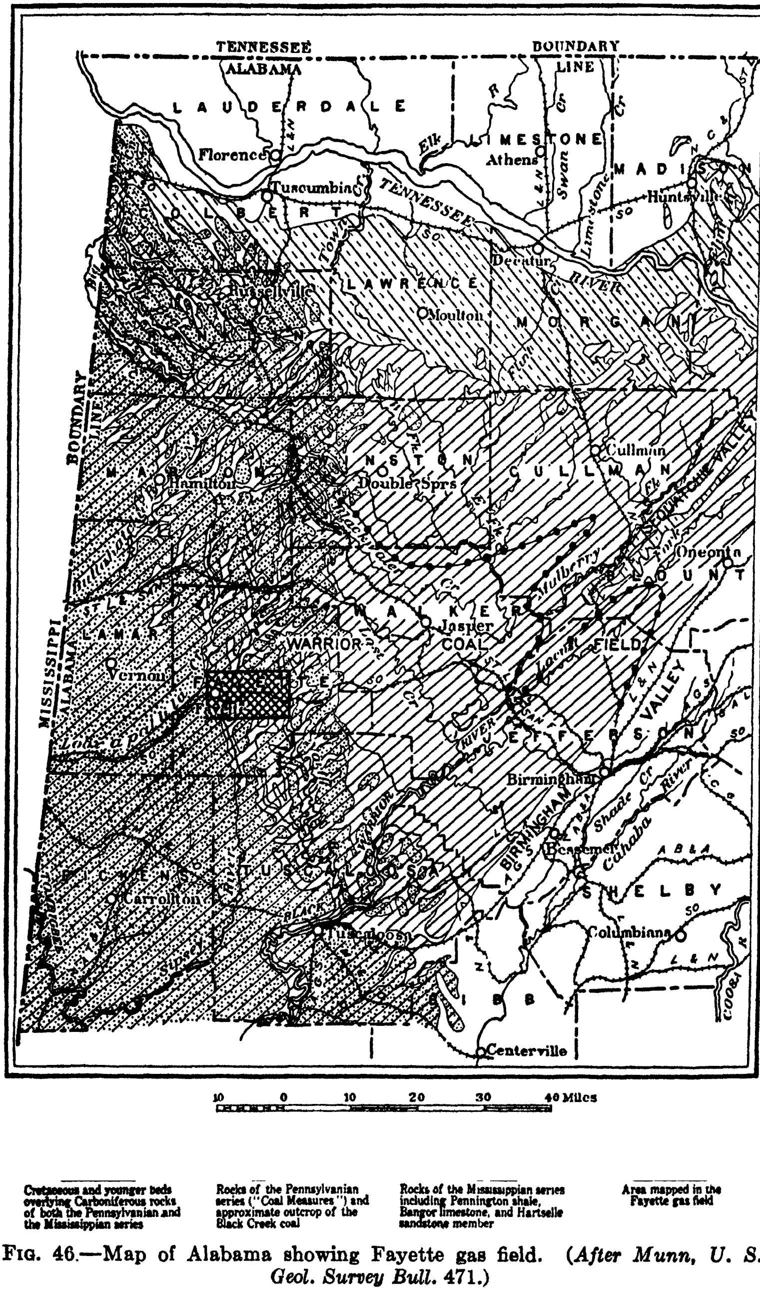

FIG. 46.—Map of Alabama showing Fayette gas field. (*After Munn, U. S. Geol. Survey Bull.* 471.)

GENERALIZED SECTION FOR NORTHWESTERN ALABAMA

System	Formation	Thickness, feet	Character
Pennsylvanian	Pottsville		Sandstone, conglomerate, shale and coal
Mississippian	Pennington	200	Red shale, thin limestones, and sandy layers
	Bangor	500	Limestone with thin shales
	*Hartselle	150	Sandstone. Asphalt on outcrop
	Gasper	120	Oolitic limestone and shale
	Bethel	30	Sandstone
	St. Genevieve		Limestone
	St. Louis		Limestone
	Warsaw	450	Limestone. Sandy at base
	Ft. Payne	170	Chert and crinoidal limestone
Devonian	Chattanooga	30	Black and brown shale
Silurian	Brownsport	220	Green arenaceous cherty limestone. *Niagara*
	Wayne	30	Red and green shale. Thin pink limestone. *Niagara*
Ordovician	Richmond(?)	50(?)	Green arenaceous limestone. Fernvale
	Trenton		Gray limestone and calcareous sandstone
			Leipers(?), Catheys(?), Bigby(?), and Hermitage
	Black River	250	Includes Kimmswick and Carters. Limestone
	Stones River	100	Brown and grey dense limestone
	Beekmantown	900	Grey and green dolomite and limestone. Thin sandstones interbedded in upper portion. May be older than Beekmantown in part

This generalized section for northwestern Alabama was made from the records of six deep wells drilled in Colbert, Franklin, Lawrence, and Lowderdale counties of northwestern Alabama, in Wayne County of southern Tennessee, and in Tishomingo County of northeastern Mississippi. In describing the well cuttings of two of these wells (Tishomingo County wells), Bramlette says that oil showings were encountered in beds of Mississippian, Silurian, and Ordovician age. He states that more hydrocarbons

could be extracted in the laboratory from the Warsaw limestone than from any other formation, though no good porous reservoir rock is present. A small showing was found 55 feet beneath the Chattanooga in the Niagara sandy, cherty limestone. In one of the wells, several fine-grained unconsolidated sands occur in the rocks of Trenton age. On treatment with chloroform in the laboratory, a light film of oil was obtained. The limestones of Black River age give definite showings of oil and gas both in the driller's record and in the laboratory. Shows were also found in one well drilled in Alabama and in the well drilled in southern Tennessee. This, therefore, seems to be a horizon that is worth more consideration in future drilling operations. Finally, in one of the wells, good oil showings were found in the dolomite of Beekmantown age fully 500 feet below the top of the Black River formation.

It is reported that one of these wells—the Goyer well in S. 29, T. 7 N., R. 6 W., Lawrence County, Alabama, produced 25 barrels of oil per day when it was first opened in 1890. This oil appeared at a depth of about 1,500 feet, or about 500 feet below the top of the Ordovician.

Favorable Areas for Prospecting.—Semmes believes that no oil or gas need be expected where the carbon ratio runs higher than 65 per cent. This would rule out all that part of the state lying east and south of a line drawn through Madison, Marshall, Cullman, western Blount, western Jefferson, and Tuscaloosa counties into Shelby County, thence following the crystalline area (see Fig. 46, p. 124).

Mississippi.—On Oct. 5, 1926, a large gas well was brought in 6 miles east of Amory in Monroe County in northwestern Mississippi. This well produced over 4,000,000 cubic feet per day. About 1 year later another gas well was brought in at a point about 15 miles southeast of Amory which was capable of producing about 3,000,000 cubic feet of gas per day. The depth to production in the first well is 2,470 feet and in the second well 2,693 feet. These wells are located very nearly on the projected axis of the Cincinnati arch (see Fig. 36, p. 94).

The rocks in this part of Mississippi belong to the Cretaceous system and the Tuscaloosa formation. The Cretaceous rocks are about 600 to 700 feet thick near Amory. In the wells, rocks of Pottsville age were penetrated to a depth of 1,468 feet. Below the Pennsylvanian rocks, the record shows Mississippian rocks down to a depth of 2,470 feet where a sandstone was encountered

which is correlated by Jillson with the Hardinsburg sandstone of western Kentucky, and of middle Chester age. It is the same as the Hartselle sandstone of Alabama which is characterized by asphalt on the outcrop.

In *Bulletin* 641, O. P. Hopkins describes the structure of the Vicksburg-Jackson area with special reference to oil and gas possibilities. The stratigraphy in that part of Mississippi is as follows:

System	Series	Formation	Thickness, feet	Character
Quaternary	Pleistocene		150	Loess and alluvium, clay, sand, gravel
Tertiary	Pliocene		50	Terrace sand and gravel
	Oligocene	Catahoula	75	Unconsolidated sand, sandstones, clay, and some lignite
		Vicksburg	80 to 130	Marl and clay above, limestone and impure limestone and marl below. Used as key horizon for structure mapping
	Eocene	Jackson	500(?)	Sand and clay
		Claiborne	500 to 1,000	Marls, sands, clays, and lignite above, quartzite, claystone and marl below
		Wilcox	850 to 1,500	Lignitic clays and sands with sand predominating in middle part
		Midway	100 to 300	Clay, micaceous sandstone, with hard limestone and sandy marl below
Cretaceous	Upper	Ripley	50 to 300	Sands, clays, marls, and impure limestones of marine origin
		Selma	600 to 1,000	Chalky limestone with argillaceous and sandy beds
		Eutaw	350	Sands, massive and cross-bedded
		Tuscaloosa	100 to 300	Irregularly bedded sands, clays, and gravels containing clay and lignitic layers at top

Hopkins describes the structure of the region as, in general, a south-dipping monocline with local steepening or flattening of the dip and occasional reversals. By using the limestone in the Vicksburg as a key horizon, he succeeded in finding several of these structural modifications which he calls the Jackson anticline, the Vicksburg monocline and the Eldorado monocline. These are described in detail in the bulletin mentioned and the reader who wishes further information about them is referred to that publication.

Morse[1] has summarized drilling operations in Mississippi up to the year 1923 and states that 20 of the 43 wells drilled up to that time are not on favorable structure. Two of the wells

[1] See Bibliography.

drilled near the southern edge of the Jackson anticline are too shallow and two others on the same structure are not deep enough to test all the possible Cretaceous horizons, nor high enough on structure.

Two wells drilled on the Vicksburg monocline did not penetrate the Woodbine sand horizon and one well on the Eldorado anticline stopped in the upper part of the Woodbine horizon. One well was drilled on a small fold in the northeastern part of Madison County but stopped in the Eocene. Another well drilled on a small fold in southern Loundes County was abandoned at 750 feet in Selma chalk. One deep well was drilled in Montgomery County east of Winona on apparently favorable structure. It stopped at a depth of 4,260 feet in lower Cretaceous rocks. Another deep well was drilled on the fold south of Charleston in Tallahatchie County. The depth reached in this test was 3,700 feet.

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CHAPTER IV

THE EASTERN INTERIOR COAL BASIN PROVINCE

The Eastern Interior coal basin, which includes chiefly Indiana, Illinois, and northwestern Kentucky, is another one of the tectonic basins of North America which has been a favorable area for the generation of oil and gas and its subsequent accumulation in pools of commercial importance. The eastern edge of the basin extends through Indiana from the northwest corner

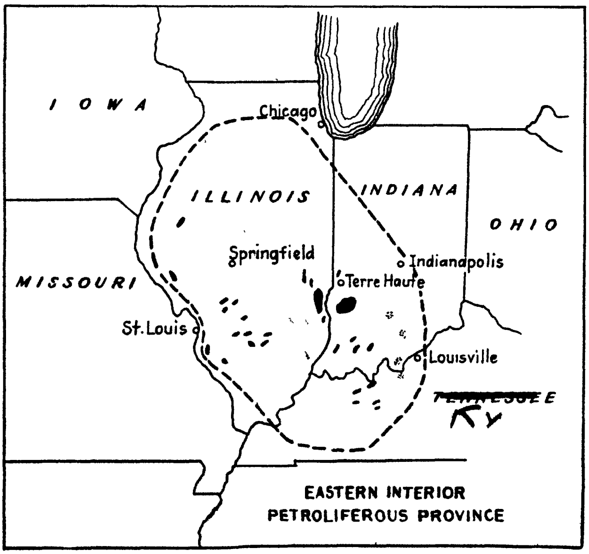

FIG. 47.—Eastern Interior petroliferous province. Solid black indicates pools in which mostly oil is found, stippled areas only gas. Province outlined by dashes.

of the state to the southeast part of the state. There it enters west-central Kentucky, and swings around to the southwest and west, and finally to the northwest entering Illinois close to the junction of the Ohio and Mississippi rivers. From there, the outer edge trends nearly northwest parallel to the Mississippi River to Rock Island County. Here, the northern edge of the

basin turns sharply toward the east until it enters northwestern Indiana (see Fig. 47).

In this basin, three areas stand out as important oil-producing areas. They are southeastern Illinois, southwestern Indiana, and northwestern Kentucky. Of the three, Illinois ranks first by a considerable margin if its importance is measured by the quantity of oil produced up to date. Naturally, the three areas show a great many common features. The stratigraphy is essentially the same, the oil horizons are very nearly the same, and the structural conditions are similar.

Tectonic Elements.—The tectonic elements which have exerted a powerful influence on the migration and accumulation of oil in this basin are the Cincinnati and La Salle anticlines, and the Rough Creek fault zone. The Cincinnati anticline forms the eastern and northeastern rim of the basin and has undoubtedly been the cause of a great deal of oil migration from the part of the basin which lies in central and northern Indiana. The fields which have resulted from such migration have been described in Chap. III. The Rough Creek (see Fig. 32) fault zone is a zone of rock disturbance which trends nearly east and west through western Kentucky. It can be traced from Shawneetown, Ill., toward the east as far as the falls in Rough Creek. There it seems to connect with a similar zone of faulting which crosses the Cincinnati arch and has been called the Kentucky River fault and uplift which, in turn, can be traced nearly to Irvine. Along the Rough Creek disturbed zone, faults have been noted at various places some of which have a throw of several hundred feet. Mostly the downthrow is on the north side, but often it is the opposite side and at many places only folding has been noted (see p. 83).

The most important structural element of a positive nature in the basin is the La Salle anticline, named from the county by that name in north-central Illinois. Figure 48 shows this anticline from La Salle County south as far as Wabash County. It also shows that the west slope of the anticline is very steep, which suggests faulting, especially in Douglass and Coles counties and perhaps in eastern Richland County. The axis of the fold shows a pitch toward the southeast of over 1,000 feet in a distance of 220 miles or at the rate of about 45 feet per mile. In Wabash, Lawrence, and Crawford counties, several small domes are superposed on the axis, thus producing more reverse dip in that

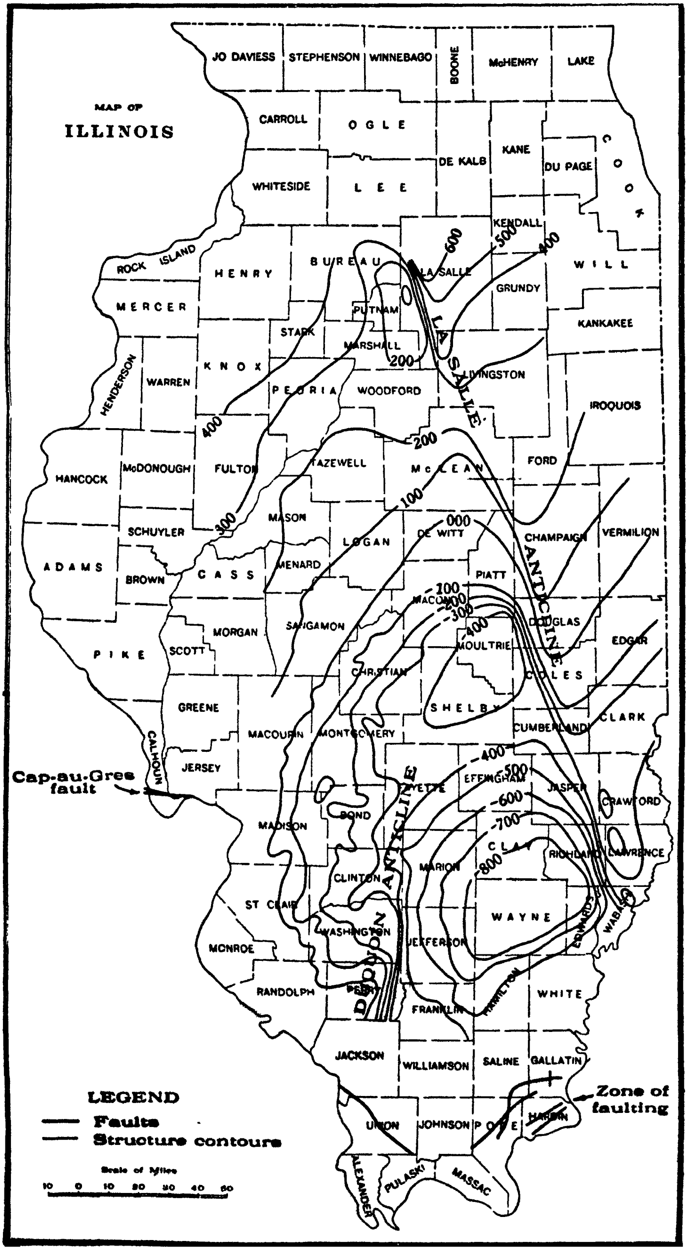

FIG. 48.—Generalized structure map of Illinois, contours on approximate horizon of No. 2 coal. (*After Moulton, Rep. Invs.* (No. 4), *Ill. Geol. Survey.*)

part than farther north. Finally, the axis plunges rather sharply at the south, which is also a favorable factor in promoting oil accumulation.

In addition to the positive tectonic elements described above, there are several negative elements which deserve mention. The most pronounced modification of this kind is the canoe-shaped basin in south-central and southeastern Illinois. This begins to show up prominently in Bureau and Putnam counties and trends southeasterly toward Moultrie and Shelby counties where it flattens out somewhat, continuing south to Wayne County, where the deepest portion lies. Another, much flatter, basin is located in Indiana. It trends nearly north and south through the western part of the state.

Stratigraphy.—Most of the Eastern Interior coal basin has rocks of Pennsylvanian age on the surface whence it derives its name, as these are the rocks which contain the coal beds. Around the borders of the basin, Mississippian rocks crop out in relatively narrow bands. This is true except on the north side of the basin where older rocks—Devonian, Silurian, and even Ordovician—adjoin the Pennsylvanian strata. In the deeper parts of the basin, the Pennsylvanian strata are over 1,000 feet thick and in places may attain a thickness of nearly 2,000 feet. The Mississippian strata vary considerably in thickness because erosion has removed a considerable portion and also because the strata overlap to some extent from west to east. For instance, in the Ditney quadrangle in southwestern Indiana, the Mississippian strata measure only 325 feet in thickness, whereas farther west in the Belleville-Breeze quadrangles in southwestern Illinois the same system measures 1,400 feet.

The Mississippian and Pennsylvanian strata are the most important systems in this basin from the standpoint of oil production, inasmuch as over 95 per cent of the oil has been derived from them. The Mississippian takes rank over the Pennsylvanian, for it has contributed between 60 to 80 per cent of the oil. In the Pennsylvanian system, the Pottsville sands are by far the most important. In the Mississippian system, the *Tribune member* of the Chester formation has furnished the most horizons of large productivity, but the St. Genevieve of Meramec age is nearly of equal importance.

Rocks of the Devonian, the Silurian, and the Ordovician systems have been penetrated in a number of deep borings. The

Devonian system is not very thick and in the main oil-producing region is only about 150 feet in thickness. Farther west it becomes much thinner and may be entirely missing at the west edge of the basin. The Silurian is of about the same thickness as the Devonian and it also thins out and disappears toward the western side of the basin. The only producing horizons found in these two systems are the Corniferous and the Chattanooga formations. The former has produced a little oil in Indiana and the latter also a very little in Kentucky. The Ordovician rocks are very thick, although figures on the total thickness are scarce. Probably over 1,000 feet of rocks belonging to this system are present over most of the basin. The massive limestones which belong near the middle of the system, called Trenton, Black River, etc. along the western edge of the basin and Galena, Plattin, Kimmswick etc. in the western part of the basin, have been the hope of the driller for years because of the wonderful production from the Lima and eastern Indiana fields, but up to date no important production has been found at this horizon near the center of the basin where the producing areas lie.

Twenty years ago, this petroliferous province accounted for approximately 20 per cent of all the oil produced in the United States. Thereafter, with the opening up of prolific areas in the Mid-continent fields and in California, the importance of the province became subordinate. In 1929, about 6,000,000 barrels were produced out of a total of over 800,000,000 barrels for the nation, thus representing about 1 per cent. During the years from 1889 to date, so many scattered wells have been drilled in the Eastern Interior Coal Basin province that no hope remains for any large virgin pools.

NORTHWESTERN KENTUCKY

The Central Interior coal basine xtends into Kentucky in that part of the state which lies west of the center (see map, Fig. 47 and 32). In this area, oil and gas have been found in small amounts at a number of somewhat widely scattered points. The individual pools extend from Meade County on the northeast through Breckinridge, Hancock, Ohio, Grayson, and Muhlenberg counties to Hopkins County on the southwest. The southernmost field is the Diamond Springs gas field in northwestern Logan County. Nine of the pools are gas pools and three are oil pools. Some of the pools were drilled up years ago and have

now been abandoned; others were discovered within the last decade and are still capable of larger production and possible extension. The best pool of recent years is the Pellville oil pool of Hancock, Daviess, and Ohio counties. Total production of this field amounted to 8,000,000 barrels up to the end of 1929.

Tectonic Elements.—The controlling tectonic element in this part of Kentucky is the coal basin which trends nearly northwest and becomes deeper in the states of Indiana and Illinois. Perhaps of greater importance in its effect upon the localization of oil and gas pools is the major subordinate structure which crosses the basin from east to west. This has been named the "Rough Creek fault and uplift." It has been traced from the falls of Rough Creek more or less continuously toward the west as far as Shawneetown, Ill. Along the line of disturbed rocks many normal faults occur, as well as some reverse faults and in places there is evidence of scissors faulting. East of New Haven, where the Rough Creek fault begins, there is a similar zone of disturbance which has been called the Kentucky River fault and fold which extends roughly to Irvine and there connects up with the Irvine-Paint Creek fault and fold described in chap. II (see Fig. 32, p. 83).

On both sides of the Rough Creek zone of disturbance are subordinate basins, the northern one of which has been called the Panther Creek syncline. This syncline shows a prevailing regional dip toward the northwest, but has some minor folds in it which change or reverse the dip over small areas as, for example, the Walnut Grove anticline southeast of Pellville in Hancock County.

Stratigraphy.—Rocks of Pottsville age appear on the surface in this part of Kentucky, with Paleozoic rocks of Mississippian, Devonian, Silurian, and Ordovician age beneath the surface. The youngest rocks comprise shales, sandstones, thin coals, and conglomerate of *Pottsville* age. They vary considerably in thickness and are marked at the base by the prominent Caseyville conglomerate. Beneath this conglomerate is found the usual unconformity that separates the Pennsylvanian from the Mississippian in Kentucky. The Mississippian rocks are very thick and probably average close to 1,600 feet. They have been subdivided into a great many formations, on the basis of lithology, most of which can be grouped into three series, the Chester at the top, Meramec in the middle, and the Osage at the base.

With some of these formations we are familiar after studying the oil fields of the Cincinnati arch in western Kentucky, as for example, the New Providence shale, the St. Louis limestone, and the Hardinsburg sandstone. Most of the other formations have new names, but these names will probably be applicable in adjacent states when further studies of the stratigraphy is carried out there.

Below the Mississippian formations is found the black shale which is so widespread in the oil fields of more eastern and southern districts (see Fig. 44). It is called the "Chattanooga shale" here, but the Indiana name of "New Albany shale" is also used to some extent. This shale has thickened considerably from Allen and Warren counties, of the Cincinnati Arch province, and approaches 200 feet in thickness. The lower Devonian is represented here by a newcomer, the Hamilton limestone which together with the *Onondaga* (Corniferous) limestone is approximately 50 feet thick. The Silurian is represented by the *Niagara* limestone, called the "Louisville limestone," and is nearly 200 feet thick. Below the Silurian rocks are found the Richmond, Maysville, and Eden limestones of Cincinnatian age and below them the Ordovician massive limestones of Trenton age. In the table on page 136, which is based on publications of Jillson and Butts, a generalized section of the rocks in this part of Kentucky is given:

Producing Horizons.—In this part of Kentucky, all the oil and gas discovered to date has come from sands in the Mississippian system. One exception might be noted—the Rock Haven field in Meade County where gas is obtained from a sand lens in the black Chattanooga shale. The oldest Mississippian sand is probably the Major sand which produces oil in Grayson County in the Leitchfield pool. The *Major* sand lies close to the base of the system in the New Providence formation. The production at Caneyville in the same county probably comes from the same horizon. The Diamond Springs gas field of northwestern Logan County gets some production from a sand in the New Providence formation. Finally, the oil in the Hartford field in Ohio County appears to be derived from the same horizon.

The *Warsaw* limestone produced the gas in the old field near Cloverport, in Breckinridge County. The Barlow, Jackson, Jett, and Stephens sands produce oil in the Pellville field of Hancock, Ohio, and Daviess counties. The Jackson sand or

GENERALIZED SECTION FOR NORTHWESTERN KENTUCKY

System	Series	Formation	Thickness, feet	Oil sand
Pennsylvanian	Pottsville		350	
Mississippian	Chester, 850′	Buffalo Wallow		
		Tar Springs sandstone	15	Stephens
		Glen Dean limestone		
		Hardinsburg sandstone	20	Jett
		Golconda limestone		
		Cypress sandstone	25	Jackson
		Gasper limestone		
		Sample sandstone	15	Barlow
	Meramec	St. Louis limestone Warsaw limestone	450	Warsaw
	Osage	Rosewood shale New Providence shale	400	Major
Devonian	Upper	Chattanooga shale	200	Rockhaven
	Middle	Hamilton limestone Onondaga limestone	50	
Silurian	Niagara	Louisville limestone	170	
Ordovician	Cincinnatian		700	
	Champlainian	Cynthiana limestone	80	
		Lexington (Trenton)	270	
		High Bridge		

Cypress sandstone also produces some gas in the Diamond Springs gas field of Logan County.

TABLE OF OIL AND GAS HORIZONS IN NORTHWESTERN KENTUCKY

System	Formation	Sand	Counties where productive
Mississippian	Tar Springs	Stephens	Hancock, Ohio, Daviess
	Hardinsburg	Jett	Hancock, Ohio, Daviess
	Cypress	Jackson	Hancock, Ohio, Daviess, Logan
	Sample	Barlow	Hancock, Ohio, Daviess
	Warsaw	Warsaw	Breckinridge
	New Providence		Ohio (Hartford field), Logan
	New Providence	Major	Grayson
Devonian	Chattanooga		Meade (Rockhaven pool)

Relation of Production to Structure.—The Pellville pool (Fig. 49) located where Ohio, Hancock, and Daviess counties make a corner, has been fully described by Jillson.[1] He states

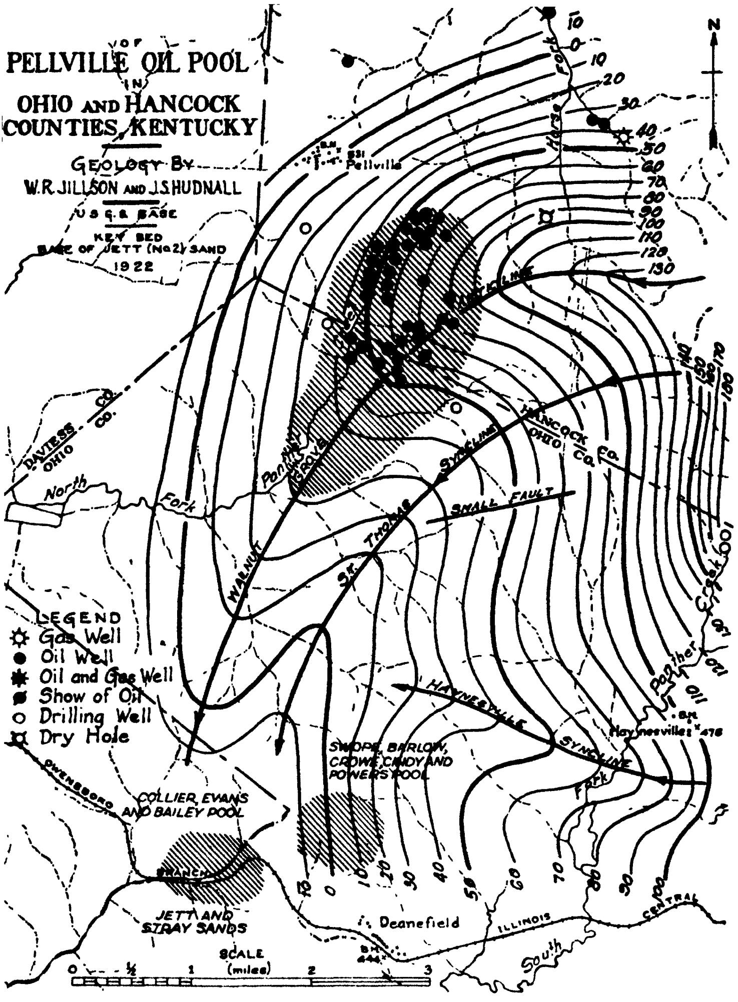

FIG. 49.—Sketch map of Pellville pool (tri-county pool) in Ohio, Hancock and Daviess counties. (*After Jillson, Ky. Geol. Survey Bull.*, Ser. 6, **12**.)

that the pool lies on the northern flank of the Panther Creek syncline which is modified near Pellville by a low plunging nose

[1] JILLSON, W. R., Geology of the Pellville oil pool, *Ky. Geol. Survey*, Ser. 6, **12**, 1926.

called the "Walnut Grove anticline." This pool was opened in 1920, oil being found in the Jackson sand at a depth of 607 feet. Most of the wells range in size from 2 to 25 barrels. Salt water has been found down the dip of the oil-bearing stratum. The Barlow, Jett, and Stephens sands also produce some oil and gas.

The Caneyville field of Grayson County, the Litchfield oil and gas field of the same county, and the Hartford pool of Ohio County all show a close relationship to the Rough Creek fault zone. This zone of rock disturbance has no doubt had a strong influence in controlling the migration of oil and gas and causing it to accumulate near by.

ILLINOIS

The oil fields of Illinois are scattered over the lower half of the state, according to the map (Fig. 47). Not all these scattered spots are producing oil in commercial quantities. The outstanding area from the standpoint of production lies in the southeastern portion of the state in Clark, Crawford, and Lawrence counties. This area has produced more than nine-tenths of all the oil produced in the state. The producing territory stretches along a narrow belt varying from a fraction of a mile to 20 miles in width, and is about 75 miles long. It will be noted that the western edge is sharply defined but that the eastern edge is highly irregular and indented. The reason for this will be mentioned later.

These rich fields of southeastern Illinois were not opened up because of the presence of oil or gas seepages, as was the case in so many of the other fields described in the preceding pages. Furthermore, much futile wildcatting was done in this part of the state before the productive portions were discovered. The first well was drilled in 1900 and was a salt-water well. Later attempts by the same company met with some slight success, but not enough to encourage them to continue. It was left to another group of men led by Colonel Carter, of Oakland, Ill., to find the rich resources beneath the soil. Their first well was drilled in 1904 on the Young farm in Crawford County and some oil and considerable gas were found. The second well was good for 35 barrels per day. This started a boom and within a year wells were being drilled within a radius of 100 miles. The intensity of this boom will be appreciated

when it is stated that the maximum production for the state, amounting to over 33,000,000 barrels of oil, was reached 3 years later.

The wells drilled in this part of Illinois were not the first wells drilled in the state, since it appears that oil and gas were accidentally found in a coal prospect near Litchfield, in Montgomery County, which led to the drilling of several shallow wells. Renewed drilling in this area resulted in the discovery of considerable oil between the years of 1882 and 1903. Gas was found in Pike County on the western side of the state in 1886, in a well which was being drilled for water. It was not utilized until 15 years later, when an area 10 miles long and 4 miles wide was exploited. In Randolph County, also in the western part of the state, a gas field was discovered as early as 1888. Since then and up to 1894 a total of 22 wells were drilled in this county.

Tectonic Elements.—The largest structural element which has had a part in the origin, migration, and accumulation of oil in Illinois is the broad basin in which the state is situated, called the Eastern Interior coal basin. The basin is divided into two unequal halves by an elongated arch or anticlinal ridge called the La Salle anticline.[1] It is an asymmetrical anticline with the steeper dip in the west flank and much gentler dips on the east side. The anticline has been traced from the northern part of the state in Stephenson County southeast toward and beyond the oil fields in Lawrence County (see Fig. 48). The axis of this structure pitches gently from north to south until the region of the southeastern field is reached, where the pitch becomes greatly exaggerated.

West of the La Salle anticline is a subordinate structural basin in Illinois which probably has its axis rather close to the anticline, as the deepest part of the basin lies in Edwards, Wayne, White, and Hamilton counties. From there the strata rise very gently toward the west with an average dip of 15 to 20 feet per mile. A sharp interruption occurs in Perry, Washington, and Clinton counties (see Fig. 51, p. 137), where a dip of 400 feet in 10 miles toward the east marks the edge of the Duquoin anticline. In the basin there are a number of prominent domes and short anticlines. One of these—the Sandoval dome[2]—has been described from Marion County, another from Montgomery

[1] WELLER, STUART, *Ill. State Geol. Survey Bull.* 6, p. 12, 1907.
[2] *U. S. Geol. Survey, Folio* 216.

County—the Litchfield dome; one from Monroe County—the Waterloo dome; one from McDonough County—the Colmar anticline. There are no doubt many others.

Stratigraphy.—The succession of rocks in the state of Illinois is divided by Blatchley[1] into three distinct stratigraphic sequences, because the section differs in different parts of the state. The only one of these that is of interest to us in this chapter is the one for southern Illinois. It begins with Quaternary deposits at the top and includes Tertiary, Cretaceous, Pennsylvanian, Mississippian, Devonian, Silurian, and Ordovician rocks, in descending order. The greatest contrast between this section and the sections given for central and northern Illinois lies in the completeness of the Mississippian and Devonian systems.

Beginning with the Pennsylvanian system, the members of the stratigraphic sequence may be described briefly as on p. 141.

The Pennsylvanian rocks occupy the greater part of the state of Illinois covering over 42,000 square miles. They are thickest in the southern part of the state where the coal basin is deepest in Wayne and adjacent counties. The uppermost formation, the McLeansboro, reaches a maximum of 1,000 feet in that part of the state. It includes all the rocks lying between the Herrin or No. 6 coal and the top of the Pennsylvanian system. A convenient subsurface marker is a zone of red shale above the Herrin coal. The *Carbondale* formation below the McLeansboro has a maximum thickness of 450 feet in southern Illinois. It is made up mostly of shale with a good deal of micaceous sandstone toward the base. The most important horizons in the formation are the Herrin coal at the top, the Murphysboro coal at the base, and the oil sands which occur at various depths within the formation. These oil sands are the shallow sands of the northern end of the prolific southeastern oil field (Coles, Cumberland, Clark, and Edgar counties).

The *Pottsville* formation has a maximum thickness of 700 feet in the southern part of the state. It contains a number of very massive sandstones by means of which it may be separated from the more shaly overlying rocks in well records. Such sandstones appear to be very lenticular and can therefore be traced from well to well only in a general way. The upper sandstone, or set of sandstones, is referred to as the Bridgeport sands in some

[1] See Bibliography, *Bull.* 22, p. 26.

GENERALIZED SECTION FOR SOUTHERN ILLINOIS OIL FIELDS

System	Formation	Thickness, feet	Character
Pennsylvanian	Mc Leansboro	500 to 1,000	Shales, sandstones, thin limestones, and coals. Producing sands of Westfield, Siggins, and Casey
	Carbondale	375	Shales, sandstones, and coals. Murphysboro coal to Herrin coal, inclusive. *Lower pay* zone in Clark County
	Pottsville	300 to 700	Mostly sandstone, some thin shales, and coals. Includes *Buchanan, Bridgeport, Robinson* sands
Mississippian	Chester	770	Sandstones, shale, and limestones, generally red shale at base. Includes *Birdsville* and *Tribune* of Weller. *Tracey, Kirkwood* and "*gas*" sands
	Cypress	80 to 150	Sandstone, massive, coarse. Irregular and thin in southeastern Illinois. Missing in Lawrence County oil fields. Unconformity at base
	St. Genevieve	80 to 100	Limestone, largely oolitic, much cross-bedding. This is the *McClosky* sand of Lawrence County
	St. Louis Salem	320	Limestone, dense, hard. Often cherty Limestone, largely oolitic
	Osage	440	*Burlington, Keokuk,* and *Warsaw.* Shale above and limestone with chert below
	Kinderhook	60	Red shale and thin limestone
Devonian	Sweetland Creek	60	Brown, black, and grey shale
	Hamilton	100	Limestone
	Onondaga	155	Limestone (Grand Tower)
	Oriskany	200	Limestone and chert (Clear Creek)
	Helderberg	165	Limestone (New Scotland)
Silurian	Alexandrian	116	Limestone and shale. *Sexton Creek, Edgewood, Girardeau*
Ordovician	Cincinnatian	100	*Orchard Creek* shale, *Thebes* sandstone, *Fernvale* limestone
	Galena-Kimmswick	500	Limestone
	St. Peter	120	Sandstone
	Lower Magnesian	545	Dolomitic limestone, thin sands, and shale

parts of the oil field and sandstones similarly located in the formation are referred to as Robinson sands in other parts of the oil fields. The conspicuous sandstones near the base of the Pottsville are called by the drillers the "Buchanan sands." Great care must be exercised in correlating the Buchanan sands, as the basal portion of the Pottsville was deposited upon a very irregular surface and no doubt many beds present at one place may be missing at another (Fig. 50).

The uppermost Mississippian rocks are of Chester age but, because of the great interval of erosion, quite a portion of the *Chester* is missing. Weller divides the Chester into the Birds-

ville and Tribune members. The upper one the *Birdsville* contains three prominent and rather persistant limestones which might be used for subsurface correlation. In the main oil fields of the southeastern part of the state, the Birdsville is entirely missing. The beds seem to thin even more to the north so that the entire Chester is missing west of a line from Decatur to O'Fallon. The *Cypress* sandstone is considered a part of the Chester formation by some geologists. Its normal position is

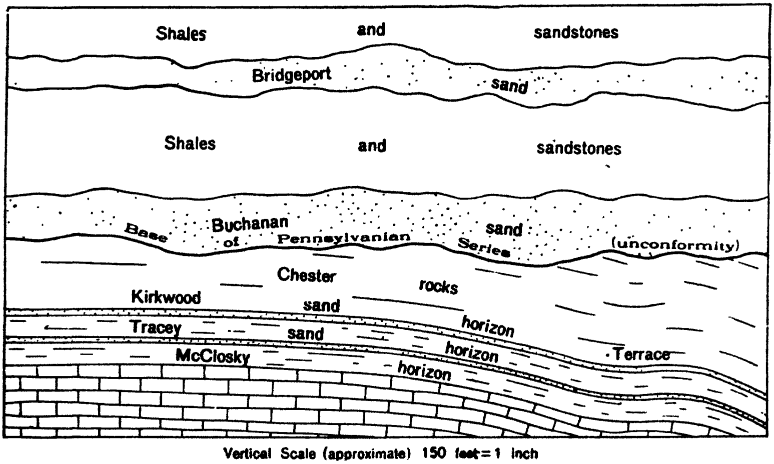

FIG. 50.—Diagram of the probable unconformable relation between the Mississippian and Pennsylvanian rocks at the south end of the oil field. (*After Ill. Geol. Survey.*)

below the Tribune, but it is also missing to a large extent in the productive areas because of pre-Chester erosion.

The *Tribune* member of the Chester formation is the *most important* formation in southeastern Illinois because it contains the most prolific producing horizons in the section. Of these the Kirkwood deserves special mention because of its wide distribution and its uniform high production. The other sands of the Tribune formation which are good producers are the Tracey sand and the "gas" sand. In general, the Tribune may be described as a series of limestones interbedded with sandstones and red shales. These red shales are prominent horizon markers for subsurface correlation and in the Lawrence field three zones of red rock are differentiated.

Below the Chester formation lies the *St. Genevieve* formation. It is composed entirely of limestone which is typically soft and

oolitic. It has an average thickness of 85 feet in the main oil fields and is difficult to separate from the underlying St. Louis limestone in the well records. Because of the porous zones in it called the McClosky sand, which has produced the largest gushers, it assumes great importance.

The *St. Louis* limestone is much harder and more cherty than the St. Genevieve, and bluish-grey in color. Because this formation and the underlying formations down to the Kinderhook are so similar in lithologic character, it is not practicable to separate them in the well records. From 600 to 900 feet of limestones are found in this portion of the log.

The nature and thickness of the remaining formations listed in the generalized section for southern Illinois oil fields must be supplied from the records of deep wells and the outcrop at somewhat distant points. The *Kinderhook* crops out at Glen Park, 23 miles south of St. Louis, Mo., where it consists of greenish calcareous shale, red shale, and pink and red cherty limestone. Some oil has been found in this formation in Clark County in what is known locally as the Carper sand.

The *Sweetland Creek* or *Chattanooga* shale has been found in the deeper wells drilled in various parts of southern Illinois. It is usually black or brown. Toward the north, it is difficult to distinguish it from the overlying Kinderhook and the two shales are frequently treated as a unit. Similarly, toward the western part of the county the black shale comes to lie above the Maquoketa shale in places where the lower Devonian and all of the Silurian rocks are missing. In such cases, it is often grouped with the Ordovician shale in well records.[1]

The great thickness of Devonian and Silurian limestone below the Chattanooga is not of interest to the petroleum geologist inasmuch as no important oil pools have been discovered in it.[2] The Ordovician Galena-Kimmswick (or "Trenton") formation may become important because in recent years deep tests have encountered commercial quantities of oil in it. The *St. Peter* sandstone may be seen outcropping at Pacific, 34 miles west of St. Louis, where it is over 110 feet thick. It is composed of well-rounded grains of translucent quartz, medium to large in size, and poorly cemented. This would seem to be an ideal oil horizon, but up to date no oil shows have been found in it.

[1] See *U. S. Geol. Survey Bulls.* 438 and 506.

[2] See MOULTON in A.A.P.G. *Symposium,* **2**, p. 132, 1929.

Producing Horizons.—The following table will give the reader a comprehensive view of the important oil and gas horizons of southern Illinois. The most important ones are starred:

TABLE OF PRODUCING HORIZONS IN ILLINOIS

System	Formation	Sand	Thickness, feet	County where productive	Remarks
Pennsylvanian	McLeansboro	Casey	5-50	Clark, Cumberland, Coles, Edgar	
	Carbondale	Shallow sands	400	Clark, Cumberland, Coles, Edgar	
	Pottsville (upper)	*Bridgeport *Robinson	0 to 300 Av. 25	Lawrence Crawford	Three lenses lenticular
	Pottsville (lower)	*Buchanan Litchfield Carlinville Petro		Lawrence Montgomery Macoupin Monroe (Centralia field)	
Mississippian		*Gas sand	0 to 68	Lawrence	
	(Tribune)	**Kirkwood	Av.30	Lawrence	Often two or three lenses
		*Tracey	80 to 150	Lawrence	
	Chester	Sparta Lindley gas sand Benoist sand		Randolph Bond (Greenville) Marion (Salem)	Same as Kirkwood
		Stein sand Biehl sand Carlyle sand		Marion (Salem) Wabash Clinton	Upper Chester Upper Chester
	St. Genevieve	**Mc Closky			Limestone
	Kinderhook	Carper sand		Clark	
Silurian	Niagara	Pittsfield gas sand Hoing		Pike McDonough	
Ordovician	Kimmswick	Trenton lime		Clark and Monroe (Waterloo)	

The *Bridgeport* sand was named from the town of Bridgeport which lies near the middle of the Lawrence County field. It may be a single sand or it may appear in two or three lenses, each one of which may be very thick. These sand lenses appear to belong in the upper portion of the Pottsville. In Crawford County, this same zone of sand lenses has been called the *Robinson* sand. An average thickness for one of the sand lenses is about 35 feet but occasionally as much as 300 feet is found. The depth at which the upper lens is found varies from 600 to more than 1,000 feet, according to surface and structural differences.

The *Buchanan* sand is found toward the base of the Pottsville but it also is very irregular in position and lenticularity. In fact, in some places the lowest lenses of the Bridgeport, or its

equivalent, the Robinson sand, seem to merge with the Buchanan sand so that a great network of interlacing sands must be visualized in the Pottsville, rather than definite stratigraphic horizons. Furthermore, the base of the Pottsville was laid down on a very irregular surface, due to post-Chester erosion and, no doubt, some sandy zones found in certain parts of the field are older and lower stratigraphically than other sandy layers called by the same name. This sand has accounted for a very great proportion of the early production of the state.

The "gas" sand is so named because it produces small amounts of gas wherever it is tapped. It also produces oil, but does not oompare in importance with the other sands mentioned previously. The thickness is somewhat variable. Blatchley reports that it varies from nothing to as much as 68 feet in the productive area. The "gas" sand is the highest producing horizon in the Chester formation. As explained above, the upper part of the Chester has been removed by erosion and the Tribune member constitutes the Chester in the southeastern oil fields. The sand lies approximately 125 feet below the top of the Tribune.

Below the "gas" sand at a depth of about 190 feet below the top of the Tribune lies the next sand—the *Kirkwood.* This sand has the widest distribution of any sand in the southeastern area and also has produced a very great proportion of the oil extracted from the area. It is not as lenticular as the Pottsville sands, but does split off into two or three lenses in places. The interval between the Kirkwood (which also lies within the Tribune) and the Buchanan sand varies from 255 feet on top of the structure to 287 feet at the southern end of the productive area showing a divergence in that direction. Even more striking is the divergence in an east to west direction, for on the western flank of the structure the interval is 450 feet. This shows a thickening of the Chester, and it is possible that the upper member, the Birdsville, comes in on the flanks.

At a depth of approximately 320 feet below the top of the Tribune lies the *Tracey* sand. It is a somewhat calcareous sand and lies close to the base of the formation. The interval between this sand and the Kirkwood also shows some divergence toward the south and more toward the west. It is not so large a producer as the others described above.

At a depth of approximately 450 feet below the top of the Tribune lies the most important oil horizon in the southeastern

fields. It is called the *McCloskey* sand from the farm on which it was first found. This producing zone is a porous phase or series of porous zones in the St. Genevieve limestone, extending through a thickness of about 80 feet. The productive pay zone, however, never exceeds 10 feet in thickness.

The *Hoing* sand, which is found only in McDonough County in the western side of the state, is interesting even though it is not very productive. It has been interpreted as a series of sand lenses of small horizontal area which fill depressions due to erosion of the underlying Maquoketa shale.

The Carper sand of Kinderhook age deserves some mention although it is of small importance as a commercial producer. It was found in Martinsville township of Clark County, in 1922, in a well which was being sent down for a deep test to the Trenton. The first well produced 125 barrels flush production and settled down to 25 barrels. Later oil was found in the top of the Devonian limestone at still greater depth.

The deepest horizon which has produced oil in commercial quantities is the so-called *Trenton* lime which probably correponds to the Kimmswick in southern Illinois. One field opened up in this zone lies in the western part of the state in Monroe County. The dome on which production was brought in is one that was recommended for drilling after the geological survey of the state had worked out the structure. In the Columbia dome, near Waterloo, the Trenton is found at 370 feet and the pay zone runs from 391 to 427 feet. The first well brought in during 1921 produced 125 barrels of 30° oil. The Trenton lime has also been found productive of small wells in Clark County in the southeastern part of the state.

Relation of Production to Structure.—In southeastern Illinois the main accumulation of oil and gas has undoubtedly been due to the presence of the steeply plunging nose of the La Salle anticline in Lawrence and Crawford counties. The largest amount of oil has been taken from the small domes and other flexures on the axis of the large tectonic element, especially at points where the dip changes abruptly. Detailed structure maps were published by Blatchley[1] for each important sand in Crawford and Lawrence counties. These maps show considerable structural modification in the form of domes, terraces, etc., which are roughly similar in different sands. On the western

[1] *Ill. Geol. Survey Bull.* 22.

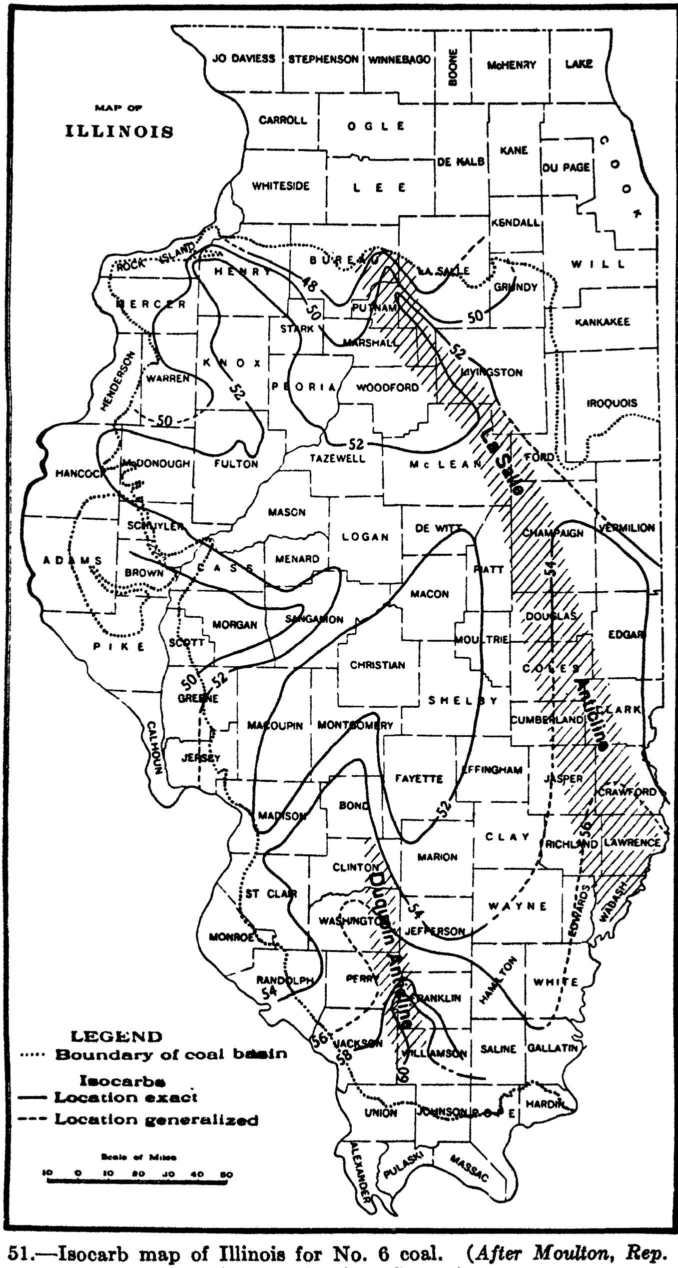

Fig. 51.—Isocarb map of Illinois for No. 6 coal. (*After Moulton, Rep. Invs.* (No. 4), *Ill. Geol. Survey.*)

edge of the productive areas the boundary is pretty sharply defined, because the dips off the main La Salle arch are steeper here and also because the water line in the sands is more clearly marked off. On the eastern side of the productive areas, the outlines are ragged and irregular, because the dip is gentle in that direction, in fact there is practically no dip for long stretches. Migration seems to have taken place chiefly from the west and southwest or from the deep part of the basin up onto the La Salle anticline. The fact that the Pottsville sands show salt water all over the fields and that the other sands show edge water along a sharp line of similar elevation on the west points to this conclusion. Furthermore, it must be assumed that the sands are fairly porous over large areas, so that migration was effected along the direction and to the extent demanded by the forces moving the oil and gas. In the Pottsville sands, this migration was most efficient because the sands and sand lenses interfinger to such an extent that porous zones were always available in the right direction. In the lower sands of Chester age, and especially in the St. Genevieve limestone, such free migration was not possible, and many barren spots are scattered through the productive portions of the fields.

In the smaller and greatly scattered pools of the rest of the state, production seems to coincide remarkably well with structure. A case in point is the Colmar field in McDonough County in which production was found in an anticline first described by Henry Hinds in his report on the Colchester-Macomb quadrangles. Similarly, the field near Waterloo in Monroe County was drilled on a dome discovered by Weller. In fact, a good deal of the successful prospecting in recent years must be credited to the intelligent guidance of the geological survey of the state.

Production Statistics, Etc.—Production of oil began in Illinois in 1889. It was small and dropped off gradually until it was reduced to zero in 1904. That was the year in which the prolific southeastern pools were found. In 1906 the production was over 4,000,000 barrels and two years later it reached the peak of over 33,000,000 barrels. Since then the production has decreased somewhat and now amounts to about 7,000,000 barrels annually. The production per acre for certain sands is of interest for comparison with other parts of the country. This was calculated by Kay and his tabulation follows:

TOTAL PRODUCTION PER ACRE FOR TYPICAL AREAS[1]

Sand	Depth, feet	Period, years	Barrels
Casey	350	10	5,309
Robinson	900	9	719
Bridgeport	800 to 1,150	9	8,390
Buchanan	1,150 to 1,350	10	36,233
Kirkwood	1,350 to 1,650	9	2,546
McClosky	1,750 to 2,000	8	15,672

[1] Kay, F. H. (see Bibliography).

Kay also states that up to the beginning of 1917, the 230 square miles of oil-producing territory in Illinois had accounted for about 1,830 barrels of oil per acre, and that on some of the farms in Lawrence County where production is secured from four sands, the total will run as high as 60,000 barrels per acre.

INDIANA

The oil fields of the state of Indiana are scattered over the whole state as the map (Fig. 47) will show. By far the most important area is the Trenton field in the eastern part of the state centering around Blackford County. From there small fields radiate toward the northwest and the southwest. Very few of these fields have commercial importance except those in the southwestern corner of the state. In Sullivan and Gibson counties especially, considerable amounts of oil have been taken out of the ground. Next to the counties mentioned, some oil has also been produced in Pike, Vigo, Dubois, Daviess, and Knox counties. In the northwestern part of the state, small quantities of oil have been found in Jasper, Porter, Lake, Fulton, and Noble counties.

The oil fields of the eastern part of the state have been discussed in the chapter on Fields of the Cincinnati Anticline. In this chapter, the fields of southwestern Indiana will be considered. They form a natural extension to the fields of southeastern Illinois, are marked by similar structural conditions, and produce oil from horizons of similar age. The exceptions to these statements will be noted later. Oil was first found in this part of the state, in 1899, when the Loogootee pool in Martin County was opened up. Three years later a more important pool was

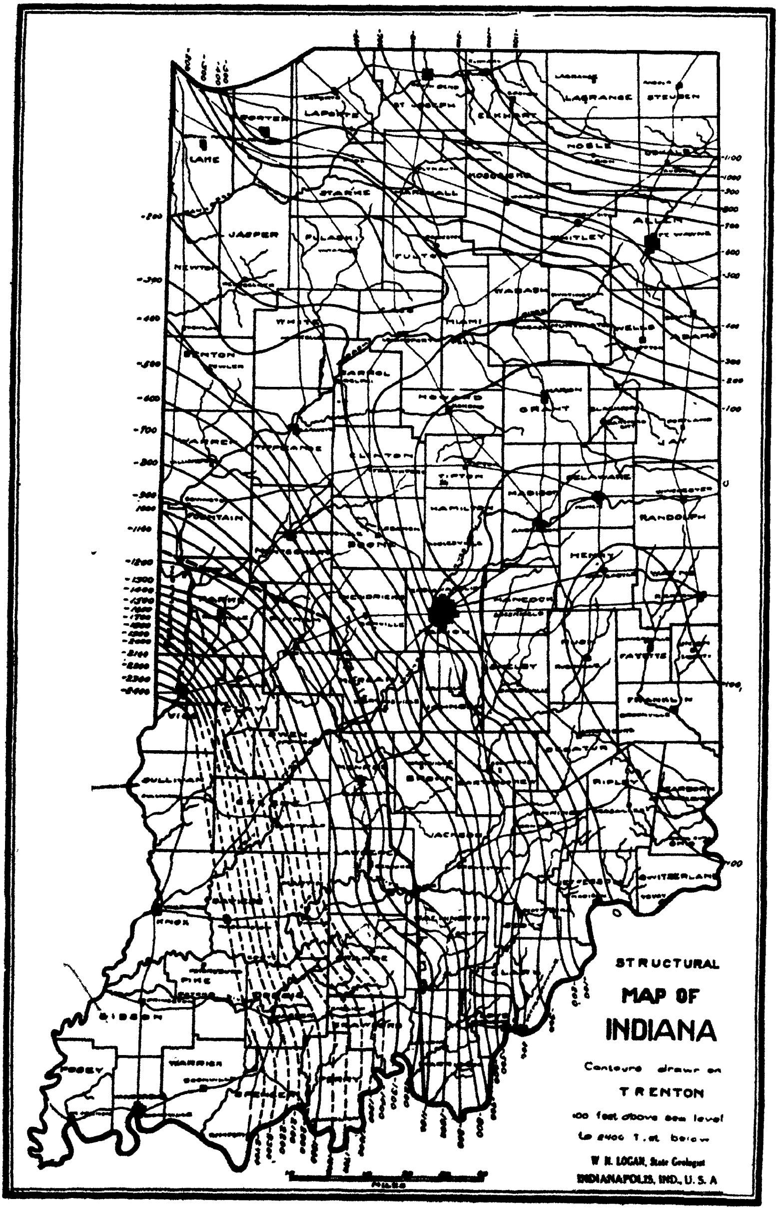

FIG. 52.—Structural map of Indiana with contours drawn on top of Trenton limestone. (*After Logan, Ind. Dept. Cons.*)

discovered in the center of Gibson County—the Princeton pool. Since then about 15 other pools have been found and the production from this part of the state is now over three-fourths of the total for the whole state.

Tectonic Elements.—The largest structural element in Indiana is the Cincinnati anticline. It enters the state at Lawrenceburg, in Dearborn County, in the southeastern corner and trends northwesterly through Franklin, Fayette, and Henry counties. There it turns nearly north and passes through Deleware County to Grant County where it resumes its northwesterly course passing thence through Wabash, Miami, Cass, Pulaski, Jasper, and Lake counties. It pitches toward the north and northwest, the rock dropping about 500 feet in the distance from southeast to northwest in Lake County. The prevailing dip west of the Cincinnati arch is at the rate of about 25 feet per mile and is directed nearly to the west. No considerable interruption of the dip is noted until the Mt. Carmel fault zone is reached. This fault zone extends nearly north and south through Hendricks, Morgan, Monroe, and Lawrence counties. The amount of throw varies, but reaches 200 feet in places and the downthrow is toward the east. Thereafter, the dip resumes toward the west and suffers no further interruption until the Wabash River is passed. Beyond that river, a reverse dip sets in, though it is slight, and finally the strata are seen to be dipping east because of the influence of the La Salle anticline of eastern Illinois. The Cincinnati arch thus forms the eastern edge of the great basin in which the coals of the Eastern Interior coal field have been laid down and which reaches west beyond Illinois into Missouri.

Stratigraphy.—The table of formations shown on p. 152 will give the reader a picture of the rock succession in Indiana with especial reference to the western and southwestern part.

In the oil fields of southwestern Indiana, the Pennsylvanian rocks are exposed on the surface. These rocks down to the base of the Pottsville are about 1,200 feet thick. For surface mapping, the Sommerville limestone is a very usable key bed. Some of the coals may also be used, coal No. 5 being considered most reliable. The geological map of Indiana will show the areal distribution of the formations. The Mansfield sandstone at the base of the Pottsville is mapped separately. This is one of the oil sands, and probably corresponds to the Buchanan sand in Illinois. In the Pottsville there is also another

System	Series	Formation	Member	Character
Pennsylvanian	Conemaugh	Shelburn	Somerville	Limestone
	Allegheny			Shales, sandstones, and coals
		Brazil *Mansfield		Shales, sandstones, and coals Mostly sandstone
Mississippian	Chester	Randolph	*Tar Springs	Sandstone
		Stephensport	*Glen Dean *Hardinsburg Golconda Indian Springs *Cypress	Limestone Sandstone Limestone Shale Sandstone.
		West Baden	Beech Creek *Elwren Reelsville *Brandy Run Beaver Bend *Mooretown *Paoli	Limestone Sandstone Limestone Sandstone Limestone Sandstone Limestone
	Meramec	*St. Genevieve St. Louis Salem Warsaw	Fredonia St. Louis Salem Harrodsburg	Limestone Limestone Limestone Limestone
	Osage	Keokuk Burlington	 New Providence	Sandstone and shale Shale
	Kinderhook		Rockford	Limestone
Devonian	Senecan	Portage-Genesee	*New Albany	Black shale
	Erian	Hamilton *Onondaga	 *Jeffersonville	Limestone Limestone
	Oriskany	Schoharie	Pendleton	Sandstone
Silurian	Cayugan Niagaran Medinan	 Cataract	 Brassfield	Limestone Limestone and dolomite Limestone and shale
Ordovician	Cincinnati Mohawkian	 *Trenton	 Cynthiana	Shales and thin limestones Limestone

sand somewhat higher up which occasionally produces oil. It is a sand between the upper and lower block coal and seems to appear at nearly the same horizon as the Robinson sand in Illinois.

Below the Pottsville is present the great unconformity which has been mentioned in connection with the stratigraphy of Illinois and western Kentucky. This unconformity (and another one at the base, possibly) has reduced the thickness of the Chester formation (series) to 200 feet more or less in the oil fields region. In that formation, however, the most valuable oil sands are found. The most prominent sandstone is the Cypress. It produces some oil, but most of the time it is found

to contain water instead. The Oakland City sand is a Chester sandstone and probably corresponds in position to the Kirkwood sand of Illinois. The gas sand of Vincennes is also a Chester sand. The Mooretown sandstone, which occurs near the base of the Chester, is an important producing horizon in the Tri-county pool in Pike, Gibson, and Warrick counties. Another producing horizon in this field is the so-called "brown" sand. Esarey[1] believes this sand is in the Paoli limestone, the lowest member of the West Baden formation. The Huron formation of the older reports is probably the same as the Chester formation. Bownocker and Blatchley describe the early wells in Gibson and Sullivan counties as producing from the Huron sand.

The St. Genevieve limestone is responsible for some of the deep oil. It may be the deep sand in the Tri-county pool. The other limestones of Mississippian age do not appear to have commercial possibilities. The Devonian is represented by the ubiquitous black shale which is called the "New Albany shale." The full thickness of the shale is 100 feet, but in the oil fields this thickness is not attained. Inasmuch as it is a potential source rock of petroleum, it should be given careful consideration. Reeves[2] has analysed the physical and chemical properties of the shale and finds that in thin sections it shows resinous spores and spore cases, the abundance of which appears greater in richer shales. He found that it will produce 500 to 1,800 cubic feet of gas per ton, which is higher than western oil shales, but that the yield of oil from the shale is less than that from western shales and somewhat less than that from Kentucky.

The Devonian limestones are interesting because they produce a little oil at scattered localities as in the Terre Haute well and in Jasper and Marion counties. Such production is in the nature of a teaser as in most cases offset wells do not produce. It is the lowest horizon which has given commercial production up to date in this part of the state. It must be recalled that in the eastern part of the state the Trenton limestone which lies below the Devonian is the important oil horizon.

Producing Horizons.—In the pages which precede, some of the producing horizons have been discussed. It will clarify their position if we arrange them in order. For that reason the following table is presented:

[1] ESAREY, see Bibliography.

[2] See Bibliography.

TABLE OF PRODUCING HORIZONS IN SOUTHWESTERN INDIANA

System	Formation	Sand	County and field where productive
Pennsylvanian	Pottsville	Shallow	Sullivan
		*Mansfield	Sullivan, Gibson, and Pike
Mississippian	Chester	Tar Springs	Pike, Davidson deep sand
		Hardinsburg	Gibson, Hoover gas sand, and Hightower shallow sand
		*Cypress	Hoover oil sand and Mt. Olympus sand in Gibson County
		Elwren	Pike County, Barker field
		Brandy Run	*Sample sand* in Oatsville pool of Pike County and Mt. Olympus and Francisco pools of Gibson County
		*Mooretown	Pike County, Oakland City and Barker pools Gibson County, Wheeling and Hoover pools
		*Paoli	Pike County, the *Brown* sand in Oakland City pool Knox County, Monroe City pool
	Meramec	St. Genevieve	Gibson and Pike counties
Devonian	Onondaga	Corniferous	Vigo, Jasper, and Marion counties

The most important sands are the Mansfield, Brandy Run (or more commonly called the "Sample sand"), the Mooretown, and Paoli. The Mansfield sand produces small quantities of oil in Sullivan, Gibson, and Pike counties. The Cypress sandstone is the producing horizon in the Mt. Olympus pool of Gibson County and also in the Hoover pool of the same county. The Mooretown sandstone is probably the most important producing horizon. It is the deep sand in the Hightower pool of Gibson County, the Oakland City sand of Pike County, and the Petersburg sand of the same county. The Paoli sandstone produces oil in the Oakland City pool where it is called the "brown sand" and also in the one important pool in Knox County—the Monroe City pool.

The *Huron* sand was the first to be identified in well drilling. It was productive in the old Loogootee pool of Martin County

and later was found in the Princeton field in Gibson County. This name probably applied to several different horizons in the Chester formation. In places, it may be the same as the Mooretown sand which has been found recently in the Tri-county pool where it averages 20 feet in thickness. The *Sample* sand has recently been found productive in the Francisco pool, located 6 miles east of the old Princeton pool and opened up late in 1926. The first well produced 150 barrels at 1,400 feet in depth, producing oil of 28° gravity, which is somewhat low for Indiana. Quite a number of other wells were drilled subsequently which brought the production up to over 300 barrels per day, representing one-eighth of the total for the state. The oil found in the Tri-county pool in the Mooretown horizon has a gravity of 34° Bé. Lower down some production is secured from a soft limestone horizon which may be the same as the McClosky in Illinois.

In the Sullivan County pools, most of the production seems to come from Pottsville horizons especially the *Mansfield* and two shallow horizons. Along the north county line, a new pool has recently been opened up which secures its production from the Corniferous limestone at 2,185 feet.[1] Three wells had been drilled to this horizon up to July, 1927, within a radius of half a mile and all found production. The only other important production from the Corniferous previously had been the Phoenix well at Terre Haute. This well was drilled in 1889 and was a gusher attracting a great deal of other drilling in the vicinity. However, no other well was successful. The Phoenix well produced an average of 1,000 barrels per month during 12 years, and in 1908 was still good for 15 barrels per day—truly a remarkable record for a limestone well.

Relation of Production to Structure.—In southwestern Indiana, most of the pools lie on the southwest side of small terraces or domes or anticlines. This indicates that migration took place from the deeper parts of the coal basin, the oil, gas, and water moving toward the east and northeast. It will be noted from the map that Gibson County lies east and southeast of Wabash County, Illinois, and thus on the trend of the La Salle anticline. The oil in Sullivan County may have come from the east from the shallow, eastern half of the coal basin. It was trapped before it reached the La Salle anticline by the lenticularity of

[1] MOULTON (see Bibliography).

the Chester and Pottsville sands in Sullivan County. In all directions from these counties, the scattered pools seem to be smaller, indicating a local accumulation after the oil had migrated only a short distance before becoming trapped.

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THE MICHIGAN BASIN PROVINCE

The Michigan basin is a somewhat smaller basin than the Eastern Interior coal basin. The center of the basin lies nearly in the center of the southern peninsula of Michigan. The border of the basin on the south corresponds roughly to the two prongs of the Cincinnati arch. It will be recalled that this arch divides in southwestern Ohio, one prong trending northwesterly toward the southern end of Lake Michigan, the other prong trending nearly north through western Ohio to the western end of Lake Erie where it turns northeasterly. On the east, north, and west, the basin is bordered by Ordovician and middle Silurian rocks which make almost a complete circle. The Great Lake basins of Michigan and Huron lie within this larger circle and are located where the relatively less-resistant upper Silurian sediments were removed by erosion. Still farther within the basin and dipping inward from all points of the circle are Devonian, Mississippian, and Pennsylvanian rocks.

The oil fields of the Michigan basin number three at present, but active drilling and prospecting has been carried on only a short time and probably other fields will be opened in the future. The three fields which are now producing oil in commercial

quantities are the Saginaw, Muskegon, and Mt. Pleasant fields. The first is located in the eastern part of the southern peninsula in Saginaw County (see Fig. 53), the second almost opposite it on the western side of the state in Muskegon County, and the third nearly in the center of the state.

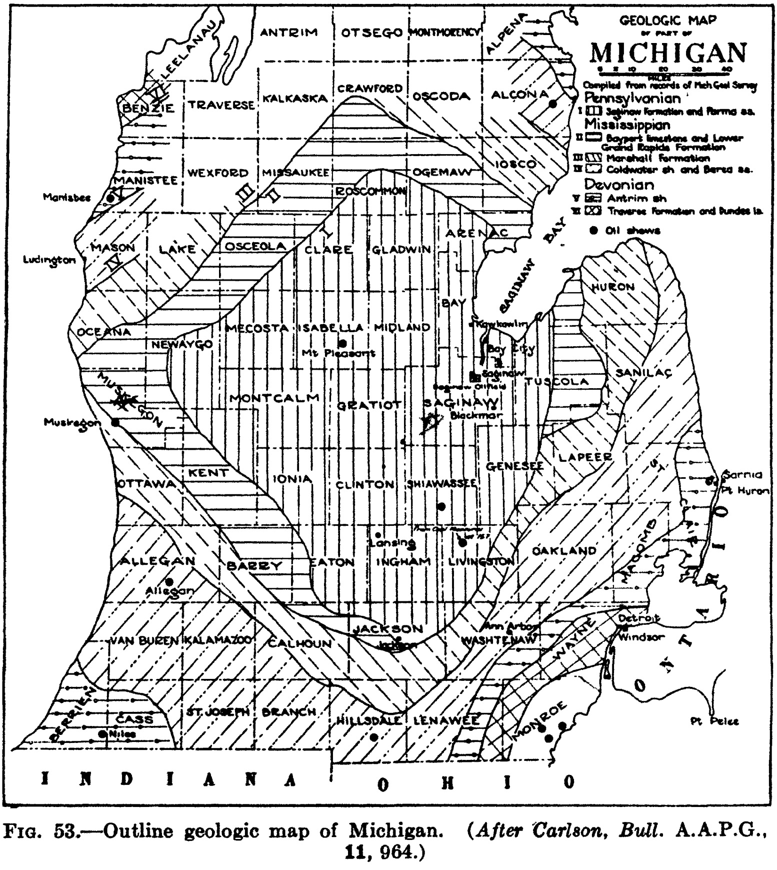

FIG. 53.—Outline geologic map of Michigan. (*After Carlson, Bull.* A.A.P.G., **11**, 964.)

Tectonic Elements.—The structure of the Michigan basin has been compared to a set of saucers fitting into each other and each being smaller than the one below (see Fig. 54). The deepest part of the basin probably lies in Isabella, Gratiot, and Montcalm counties. A number of positive structural elements of a subordinate rank have been found and described by members of the Michigan Geological Survey. One of these is the Saginaw anticline, which will be described in detail later. Another is

the Port Huron anticline in St. Clair County in the eastern part of the state at the outlet of Lake Huron. An anticlinal nose is probably present at Stony Island in the Detroit River a few miles south of the last-mentioned anticline. In Wayne County, still farther south, and in the southeastern part of the state not far from Detroit, is the Wyandotte anticline. In the southwestern part of the state an anticlinal nose trends northeast toward the deeper part of the basin from South Bend toward Kalamazoo. Other anticlines for which the evidence is somewhat meager have been found in Allegan, Manistee, and Charlevoix counties, and at Seul Choix Point in Schoolcraft County. A rather broad, low, and ill-defined arch trends north from Washtenaw County near Ann Arbor toward Fowlerville and Owasso. Inasmuch as the whole Southern Peninsula is covered with drift, these flexures were discovered chiefly by interpreting records of deep wells.

Stratigraphy.—The rocks in the Michigan basin include all systems from the Cambrian to the Pennsylvanian. Exposures of these consolidated rocks are not numerous, inasmuch as glacial deposits form a mantle over most of the state to a thickness reaching nearly 1,200 feet in places. The Pennsylvanian is represented by the Pottsville and possibly Conemaugh formations, having a total thickness of about 500 feet. The Mississippian is very thick and includes formations representing both lower and middle parts of the system. The upper part of the system is missing in most sections of the state, partly because of the erosion interval between Mississippian and Pennsylvanian times, and partly because most of it was never deposited in the basin. The total thickness of the rocks of this system exceeds 2,000 feet. The Devonian system is also thick, and all of the major divisions of the system are present. It has greater importance than the rest in Michigan, because all of the important petroleum shows and commercial pools are directly associated with its formations. The Dundee near the base has produced some oil and nearly always has a show of oil in it. The Traverse formation produces oil at Muskegon, and the Berea, which lies directly above the Devonian, probably derived its contained oil from the black shales in the system. The maximum thickness of the system is approximately 1,600 feet. The Silurian is also well represented in the Michigan basin. Limestones and dolomites make up the bulk of it and the total thickness is nearly 2,400 feet. The

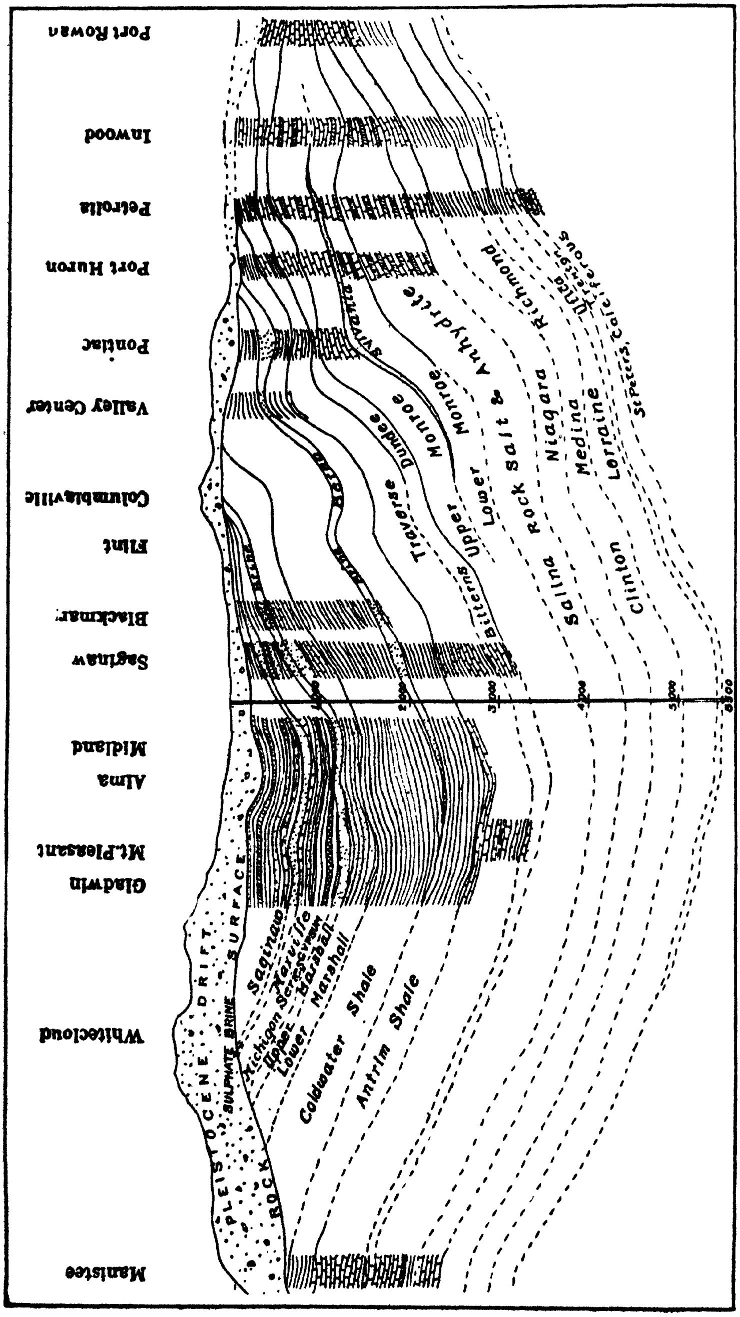

FIG. 54.—Diagrammatic cross-section of the Michigan basin from Port Huron, Ontario to Manistee, Michigan. (After Smith, Mich. Geol. Survey Bull. 14.)

usual shales and thin limestones of upper Ordovician age and the massive limestones of middle and lower Ordovician are present and can be reached by the drill around the border of the basin. The Cambrian is represented probably by the Lake Superior sandstone. For purposes of comparison with the sections in the other provinces discussed in this book the following table is presented. It is based on the work of Lane, Smith, and other members of the State Geological Survey:

GENERALIZED STRATIGRAPHIC SECTION FOR THE MICHIGAN BASIN

System		Formation	Thickness, feet	Character
		(Pleistocene)		Recent deposits of sand, etc. Glacial deposits of all kinds
Pennsylvanian	L	Woodville	110	Reddish sandstone and shale
		Parma	170	Sandstones and conglomerate
Mississippian	Upper	Bayport	235	Limestones and thin sandstones
		Michigan	300	Limestone and dolomite. Some gypsum, red and green shale
	Lower	*Napoleon	300	Sandstone. Brine or fresh water. Also called Upper Marshall. Good key horizon
		Lower Marshall	200	Sandstones red and white. Considerable shale
		Coldwater	900	Blue shale
		Sunbury	50	Black shale
		*Berea	100	White sandstone. Main producing horizon
Devonian	Neo-	*Antrim	480	Mostly black shale. Concretions of pyrite and calcium carbonate. Bituminous
	Meso-	*Traverse	600	Limestones and shales. Second producing horizon
		Bell	50	Shale, soft, blue, sometimes black
		*Dundee	250	Limestone usually very pure, hard, and massive
	Eo-	Monroe (upper)	275	Dolomite, gypsum, and limestone. Some sandstone at base
Silurian	Cayugan	Monroe (lower)	500	Dolomites, anhydrite, etc.
		Salina	900	Dolomite, salt, gypsum, red and green shales
	Niagara	Niagara	600	Dolomite white in color some massive, some thin-bedded and cherty
	Alexand.	Clinton	130	Shales, limestones, some red rock
		Medina	100	Shales, red mostly. Some sandstones and green shales
Ordovician	Cincinnati	Richmond	150	Shales and thin limestones. Mostly blue color
		Lorraine	350	Blue shales
		Utica	50	Black shales
	Mohawk	Trenton	100	Limestone
		Black River	150	Limestone
Cambrian		Lake Superior	150	Sandstone, white, red, and brown. Artesian water

The lowest formation mentioned, the Lake Superior sandstone, crops out at places in the Upper Peninsula, but has not been reached in the wells of the Lower Peninsula. It is a soft friable

porous rock and makes an excellent reservoir rock. The Trenton and Black River limestones are very persistent and may yield petroleum at structurally favored localities. The depth to the Trenton is great except around the borders of the basin. The overlying black shale makes it an attractive horizon for prospecting, especially in the southern part of the state. The shales and limestones and dolomites above the Trenton do not appear very important from the standpoint of petroleum possibilities until the massive middle Devonian limestone is reached. This is looked upon as an important reservoir of oil and gas because of the large production found at Mt. Pleasant and Muskegon. Recently Newcombe, the assistant state geologist, has found evidence indicating that the so-called Dundee limestone is in reality the upper part of the Monroe limestone. The Traverse formation somewhat higher in the section is rapidly becoming one of the important producing horizons of the state, largely as a result of the finding of oil at Muskegon. This formation is of middle Devonian age and thus lies at the same stratigraphic horizon as some of the rich oil sands in Pennsylvania. The reason for this coincidence lies in the fact that both have rich bituminous shales adjacent. In the Michigan basin, these bituminous shales are called the "Antrim shales" and they correspond to the Ohio shales of Ohio and in part to the Chattanooga of the fields farther south and southeast.

The Berea also owes its present importance as one of the producing horizons of the state to the proximity of the same body of black shales, although in the case of this sandstone some of its contained fluids may have been derived from the overlying black shale. The sandstones higher in the section, the upper and lower Marshall, and the Parma have never been known to yield oil but do contain gas. The upper Marshall is a very important key horizon for structure mapping. It may be reached at shallow depths and lends itself ideally for core-drill exploration. It contains salt water at a distance from the outcrop, and inasmuch as the water has a large percentage of bromine many wells have been drilled to this horizon in the deeper part of the basin. Near the border of the basin it carries fresh water.

Producing Horizons.—Up to the present time, four important producing horizons have been discovered in the Michigan Basin

province. They are the Berea sandstone, of lower Mississippian age, two porous horizons in the Traverse formation of middle Devonian age, and the upper part of the Dundee limestone, which is also of middle Devonian age. In the oldest pool of this province—the Port Huron pool (extreme eastern part of the Southern Peninsula)—the Dundee is the producing horizon. In the Saginaw pool the Berea sandstone and the upper Traverse horizon produce the oil. The Muskegon field, which still has undefined limits, secures its oil from two horizons in the Traverse formation and from the Dundee limestone. The very recently discovered pool near Mount Pleasant in Midland and Isabella counties near the center of the Southern Peninsula has only one producing horizon which lies in the Dundee limestone at a depth of about 35 feet below the top. Early in 1930, 80 wells had been drilled to this horizon and were capable of producing 9,000 barrels per day. The depth to production in the Mount Pleasant area is approximately 3,550 feet.

Saginaw Pool.—The Saginaw pool is located near the town by the same name in the east-central part of the lower peninsula of Michigan. First efforts to open a pool at Saginaw were made in 1912 and 1913. Some of the wells found small amounts of oil in the second sand but none were located favorably enough to tap the Berea. This sand was not found to be productive until the Saginaw Prospecting Company drilled its first producer in 1925. It produced about 20 barrels initially after a shot, and subsequently development was rapid and within a year and a half the productive area was pretty well defined. The field at present covers an area of about 3 square miles and lies beyond the Saginaw River on the northwest edge of the city of Saginaw.

The depth at which production is obtained varies from 1,800 to 1,860 feet, according to position on the structure. The oil occurs in the few uppermost feet of the Berea sand although the sand has a total thickness of nearly 75 feet. Below the pay streak is a shale break and the sand body below the break contains salt water. The initial production varies from a few to as much as 40 barrels and the decline is slow, probably due to the fine texture of the sand, as most of the grains will pass a 180-mesh sieve. The oil has a gravity of 46.3° Bé. and very little gas accompanies the oil.

A second sand was found in the Saginaw field within the Traverse formation. The position of this sand is shown in Fig. 55.

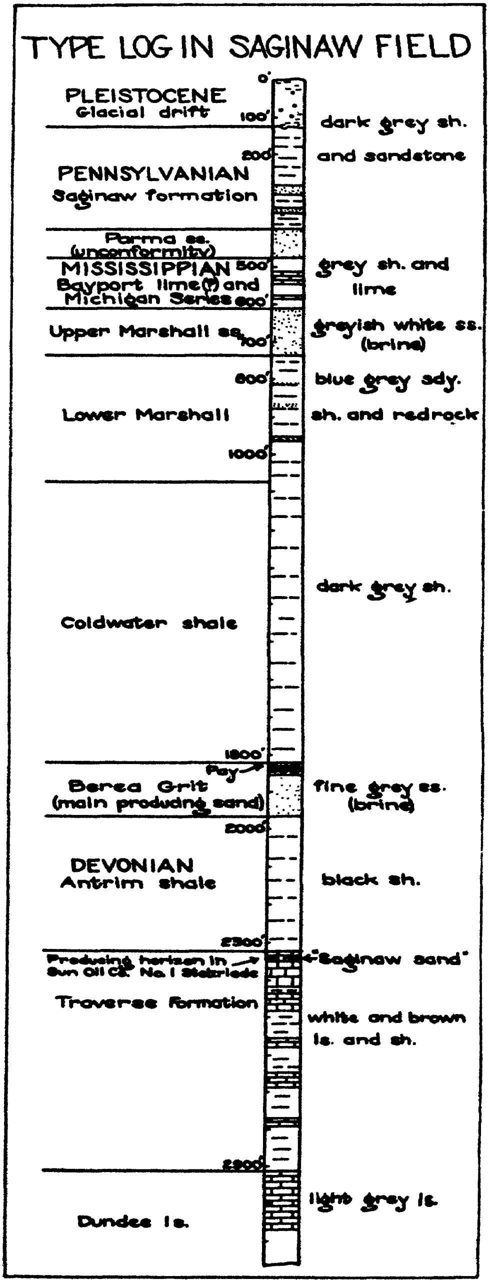

FIG. 55.—Type log in Saginaw field. (*After Carlson.*)

It is called the "Saginaw sand" because of the good shows originally found at this horizon in the early wells drilled in 1912 and 1913. The discovery well in this sand was the Stelzriede No. 1 of the Sun Oil Company, which came in for 500 barrels in March, 1927. Three months later, this well was pumping 50 barrels per day. Five other wells including one offset well were dry at the same horizon.

Several wells have been drilled to a possible third horizon—the Dundee limestone, which lies about 580 feet below the top of the Traverse formation. Some oil was found in the older wells at a depth of 35 feet from the top of the limestone in a light grey to brown crystalline limestone. This zone appeared to be free from water, but much water was found farther down in the formation. In the Port Huron field, gas was found in the Dundee limestone as early as 1886. In 1898, a fair amount of oil was found in the same area at a depth of 520 feet. The production was from 2 to 5 barrels per day, but because of the shallow depth many wells were drilled and most of them are producing to this date, showing that the sand is long lived. In Ontario, a few miles farther east, very good production has been obtained during the last 50 years in the same horizon but at somewhat greater depths in the limestone. Renewed drilling in the Saginaw field to this third sand has not met with success.

Relation of Production to Structure.—In the Saginaw field, there is a very close relationship between production and structure. Figure 56 will show that the successful wells lie on the northwest side of a pitching anticline. The general position of this anticline was described by Lane a good many years ago, and it was on the basis of his favorable remarks that the early wells were drilled in 1912. It will be noted that on the west side of the structure oil is found as low as the 1,250-foot contour line, whereas dry holes appear on the north side as high as the 1,235-foot contour line. In general, the best wells are located within the 1,220-foot contour line. These remarks apply only to the Berea sandstone. The second sand does not conform to structure so closely. It is a porous limestone and differential porosity controls production as well as structure. Only two producers have been drilled to this horizon, the larger being located in Sec. 11, on the 1,230-foot contour line and the smaller one, nearly on the highest part of the structure. Five other wells at various positions with reference to structure found the limestone non-porous and were dry in the second sand.

Muskegon Field.—Beginning in the early 'seventies, wells have been drilled in the vicinity of Muskegon on the western side of the state. One of these wells started in 1872 found oil at

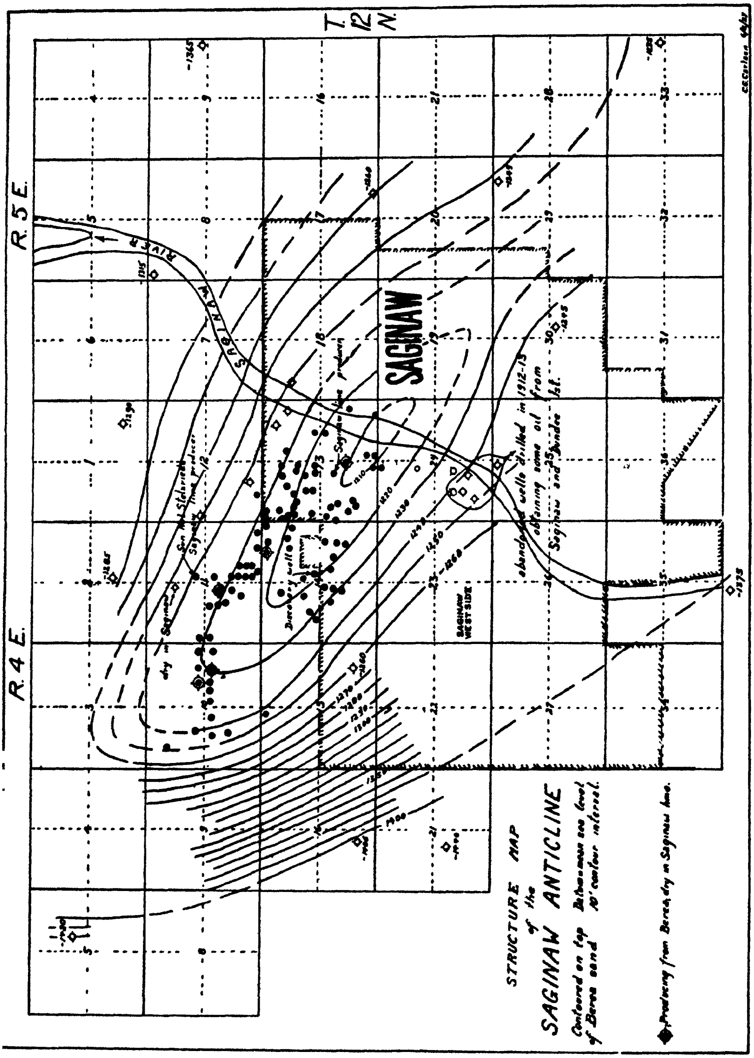

FIG. 56.—Structure map of the Saginaw anticline. (*After Carlson, Bull.* A.A.P.G., **11**, 961.)

a depth of about 1,200 feet. Two or three other wells drilled in later years also found a good show of oil at this horizon which corresponds to a sandy layer near the base of the Coldwater

formation. In 1927, renewed drilling was undertaken largely as a result of the success attained in the Saginaw field and on the strength of the early shows. On Dec. 22, 1927, the discovery well was drilled in. It started producing at the rate of 340 barrels per day from the Traverse formation, at a depth of 4 feet in the porous zone of the limestone, and was still producing 50 barrels per day in the middle of 1928. Another large well came in on June 23, 1928, at the rate of 260 barrels per day, at a depth of 1,668 feet in the Traverse formation. A gas well capable of producing 6,000,000 feet was drilled in during June with a rock pressure of 630 pounds, in the Traverse formation. Large quantities of gas and oil have also been found about 400 feet below the Traverse formation in the Dundee limestone. On the basis of these early discoveries, it now appears that there are four producing horizons in this part of the province. The Berea sandstone, which has been found productive in only one well and was very shaly and thin, lies at a depth of about 1,100 feet. The upper Traverse horizon lies at a depth of 1,600 feet, the lower Traverse horizon at 1,900 feet, and the Dundee limestone horizon at about 2,050 feet. The oil ranges in gravity from 36 to 39° Bé.

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CHAPTER V

THE WESTERN INTERIOR COAL BASIN PROVINCE

The Western Interior coal basin covers a large area in the central part of the United States. It includes southwestern Iowa, northern and western Missouri, southeastern Nebraska, eastern Kansas, eastern Oklahoma, and northern Arkansas. It lies along the eastern border of a much larger structural basin which has been called the "Rocky Mountain geosyncline basin" and is therefore not exactly comparable to the Eastern Interior coal basin or the Appalachian geosyncline. In these two, the whole basin is filled with Paleozoic sediments and the coal-bearing rocks of Pennsylvanian age crop out at the surface over most of the basin. In the case of the Western Interior coal basin, rocks of Carboniferous age were laid down over the whole basin, but they were not the last to be deposited as was the case in the other basins. Instead, rocks of Mesozoic and Cenozoic age were also deposited in the basin and they now form the surface rocks over nine-tenths of the Rocky Mountain geosyncline basin. The historical geology of the basin indicates that there are two Rocky Mountain geosynclines, one of which was a Paleozoic basin and the other a Mesozoic basin. The Paleozoic basin extended from Monzonia on the west to the positive areas of Wisconsia, Ozarkia (in southern Missouri) and Llanoria on the east. The Mesozoic basin had its eastern limits along a line which lies a considerable distance west of Wisconsia and Ozarkia. If the Paleozoic basin had a name, it might be feasible to use it for the province. The name Western Interior coal basin is chosen because it is the most characteristic portion of the basin and especially because the name suggests the location of the area to geologists.

The Western Interior Coal Basin province includes the oil fields of eastern Kansas and of northern and eastern Oklahoma. The most northerly field in the province at present is the gas field in Wyandotte County, Kansas, and the most southerly one is the Ada gas field in Pontotoc County, Oklahoma. The length of this great zone of oil and gas fields is thus approximately

250 miles. The most easterly field is the Poteau gas field in eastern Le Flore County, Oklahoma, and the most westerly one the oil pool in Trego County, Kansas. The width of the zone is therefore in excess of 300 miles.

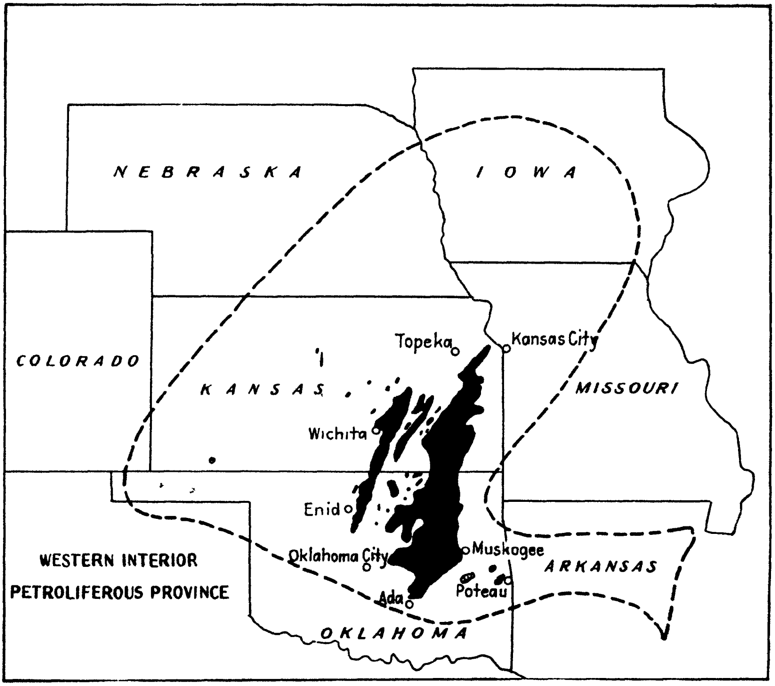

FIG. 57.—Western Interior petroliferous province. Solid black indicates oil- and gas-producing areas, stippled gas only. Province outlined by dashes.

Tectonic Setting.—In order to get the proper perspective for the tectonic setting of the oil fields in this province, the geological history of that portion of our continent which lies between the

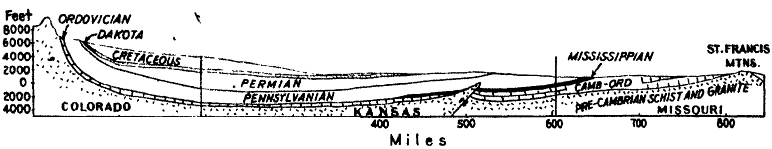

FIG. 58.—Geologic cross-section in an east to west direction across the Kansas region.

Appalachian and the Rocky Mountains must be considered in part. During the early part of the Paleozoic era, while Cambrian and Ordovician strata were being laid down in the epeiric

sea, differential subsidence was going on so that finally a thickness of many thousand feet of strata was accumulated. The zone of most rapid subsidence was a narrow one and paralleled closely the old land masses of Appalachia and Llano or Columbia (see Fig. 8). It is likely that these two land masses were united through Alabama, Mississippi, and Louisiana in early Paleozoic time. If so a synclinal trough may be visualized, extending from New England through Pennsylvania and the southern Appalachian states into northern Alabama, thence westward through Mississippi, and central Arkansas, into southern Oklahoma. North and west of this trough, subsidence was also going on but far less rapidly. In fact, certain loci were soon developed where subsidence stopped altogether for long periods of time. One of these loci was near the site of Nashville, Tenn., and another was located in southern Missouri, near the site of the present St. Francois Mountains. The Nashville dome, as was shown in a previous chapter, became the nucleus of the Cincinnati arch. The area in southern Missouri formed the nucleus for a very large dome which has been called the "Ozark dome."

The area of the Ozark dome subsided during Cambrian time when much sandstone and even more limestone was deposited. It continued to subside during early Ordovician (Canadic) time, so that at the end of the period over 4,000 feet of strata had accumulated. With the deposition of the Jefferson City limestone, subsidence stopped and a large portion of the Ozark dome became land. All of it remained above water during middle and upper Ordovician, Silurian, and Devonian times. The Mississippian seas then encroached upon the borders of the dome, but the central portion remained land during all succeeding periods of time up to the present.

While the Ozark dome remained elevated, relatively, with reference to surrounding areas, it is found that other portions of the continent nearby remained elevated with it. One such positive structural element (the Chautauqua or Ozark arch) begins in southwestern Missouri and extends through northern Oklahoma and southern Kansas as far west as Kay and Cowley counties, respectively. There it either meets a northsouth trending element of similar nature and age, or else turns southward through Noble, Logan, and Oklahoma counties. The data in this part of the province are incomplete, but it probably

continues southward through McClain, Stephens, and Cotton counties into Texas, where it unites with the Bend arch. (It may unite with the Hunton arch in Pontotoc County.[1]) This large structural element came into existence during upper Ordovician time and functioned as a land mass during Silurian and Devonian times. But in the Mississippian period, water covered this arch as well as large parts of the Ozark dome.

Nemaha Mountains and Barton Arch.—Deep-well records of Kansas have uncovered evidence of two other areas which

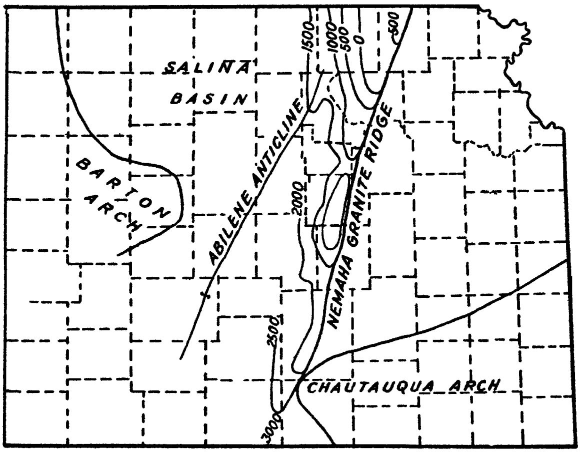

FIG. 59.—Prominent structural features of pre-Pennsylvanian strata of eastern and central Kansas.

remained relatively higher than surrounding areas, during the gradual subsidence of the continental mass. One of these has been called the Nemaha Mountain ridge and the other the Barton arch. These are described in detail on pages 180 and 184.

Salina Basin.—Closely related to these two structural elements is the Salina basin, named by Barwick. The area between the Nemaha granite ridge and the Barton arch was an area of continued subsidence after Ordovician time, for it contains Silurian, Devonian, and Mississippian sediments. Figure 59 shows this basin and the positive structural elements lying to the east and west of the basin. Three cross-sections, shown in Figs. 60, 61, and 62) are reproduced from Barwick's paper to show the attitude of the rocks across the basin from east to west and from

[1] See DOTT, *Okla. Geol. Survey Bull.* 40.

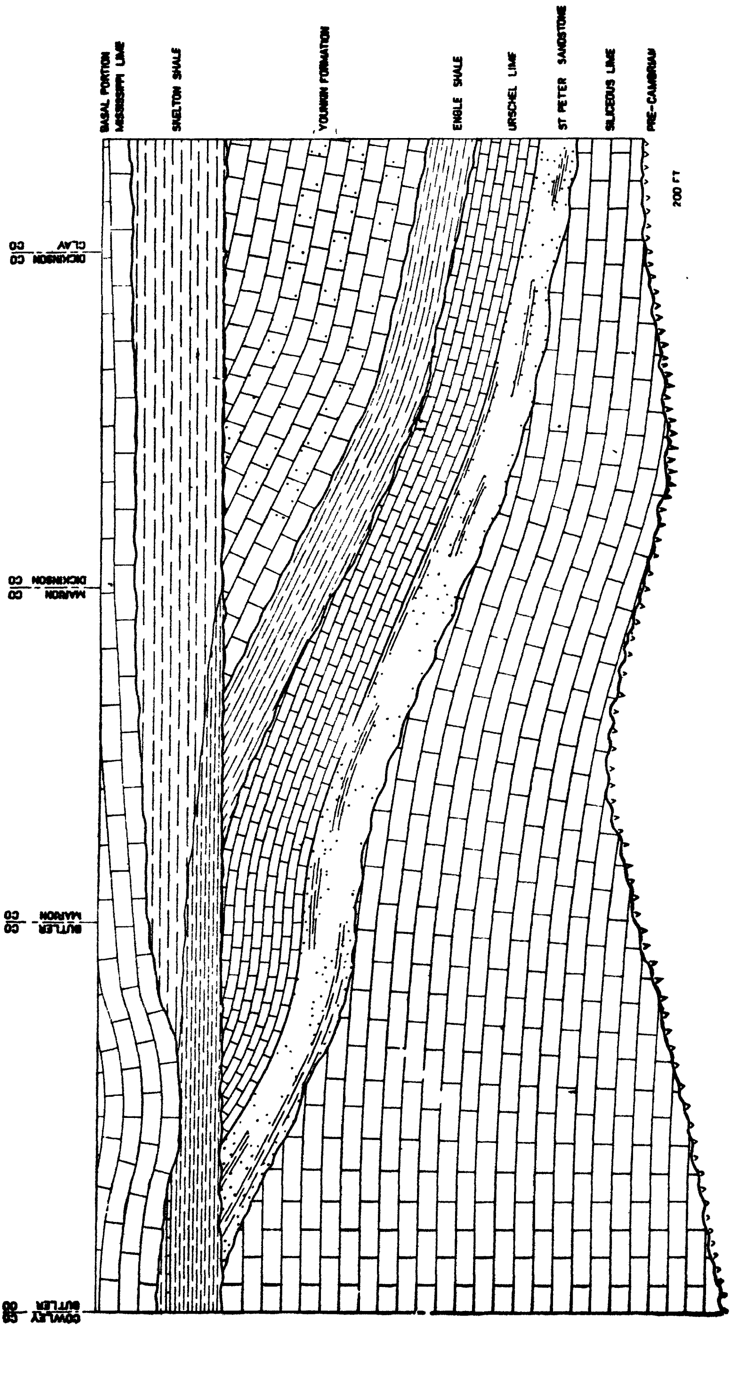

FIG. 60.—Generalized cross-section from north to south in the Salina basin. (*After Barwick, Bull.* A.A.P.G., **12** (No. 2), 182, Fig. 2.)

north to south. The details brought out in these sections will be discussed further under the heading of Stratigraphy.

Ouachita-Arbuckle-Wichita-Amarillo Mountain Chain.—In the great Appalachian trough described above as probably extending into east central and southeastern Oklahoma, subsidence was rapid and great. During the Silurian and Devonian

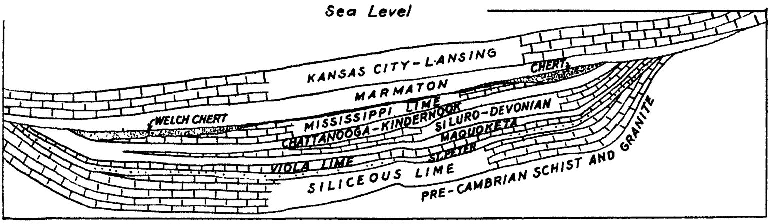

FIG. 61.—East-west section across the Salina basin. (*After Barwick, Bull.* A.A.P.G., **12** (No. 2), 187, Fig. 3.)

periods subsidence was not particularly notable, but in Pennsylvanian time it was indeed remarkable, for as much as 18,000 feet of material was accumulated in the deeper portions of the trough close to the old land mass of Llano. These sediments consist of shale and sandstones for the most part with but subordinate amounts of limestone. Evidently, the foundering

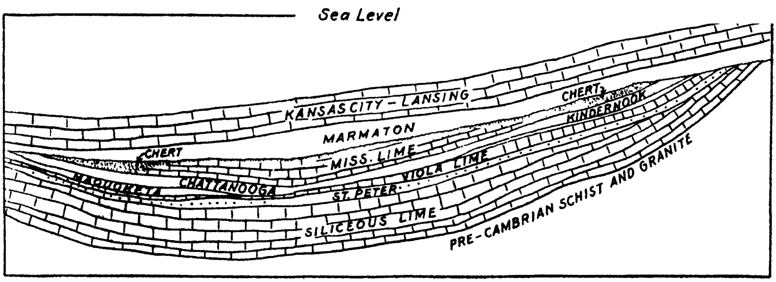

FIG. 62.—Same as Fig. 61, but farther south.

of the continental segment of Llano culminated about the middle of the Pennsylvanian period and compressed the rocks (which had been formed during earlier periods) within a narrow zone in southern Arkansas and southeastern Oklahoma. This resulted in long, narrow, parallel lines of folds and faulted folds which were subjected to rapid erosion probably concomitantly with their formation. It also resulted in the abnormally rapid

subsidence of the foredeeps which lay to the north in the present Arkansas valley area. Uplift, erosion, and subsidence, therefore, went on simultaneously, producing the Ouachita Mountains of central Arkansas, and the Arbuckle Mountains of southern Oklahoma.

In these mountains there is considerable evidence of diastrophism during upper Ordovician time similar to that of the southern Appalachian region. Shear faulting on a grand scale seems to have been a characteristic feature of this disturbance. Thus, the ancestral Ouachitas and Arbuckles were produced in the basin lying east of the Ozark arch. West of the Ozark arch similar shear zones formed during upper Ordovician time and probably at the close of the period brought up great segments of the granitic basement rock in the Wichita and the Amarillo mountains. These four mountain tracts with the connecting areas, therefore, form a tectonic unit which borders the Western Interior coal basin province on the south.

Stratigraphy.—The succession of rocks in the area involved in this province is not greatly dissimilar from that in the provinces farther east. The same systems are involved and the great unconformities are comparable and occur at about the same horizons. At the top of the section are found Permian strata. In Kansas, these have been divided into two series, the *Cimarron* and the *Big Blue*, each of which in turn is divided into four formations.

The Pennsylvanian rocks crop out in eastern Kansas, eastern Oklahoma, and west-central Arkansas (see Fig. 63). They change so greatly in that area that it is difficult to trace the Kansas formations very far south of the state line. In general, the limestones are thickest in the northern part of the area and become thinner toward the south. Many of them finger out before they reach the state line and the two shale bodies above and below merge. Again, toward the south the shale changes to sandstone at numerous horizons in the section. Finally, to complicate matters further, the whole section of Pennsylvanian strata becomes very much thicker toward the south. This is partly due to overlap toward the north. In other words, a large part of the lower Pennsylvanian of southern Oklahoma is missing farther north, and the Cherokee of Kansas, therefore, represents only some of the upper Pennsylvanian strata of Oklahoma. The thickening of the section is also due in part to

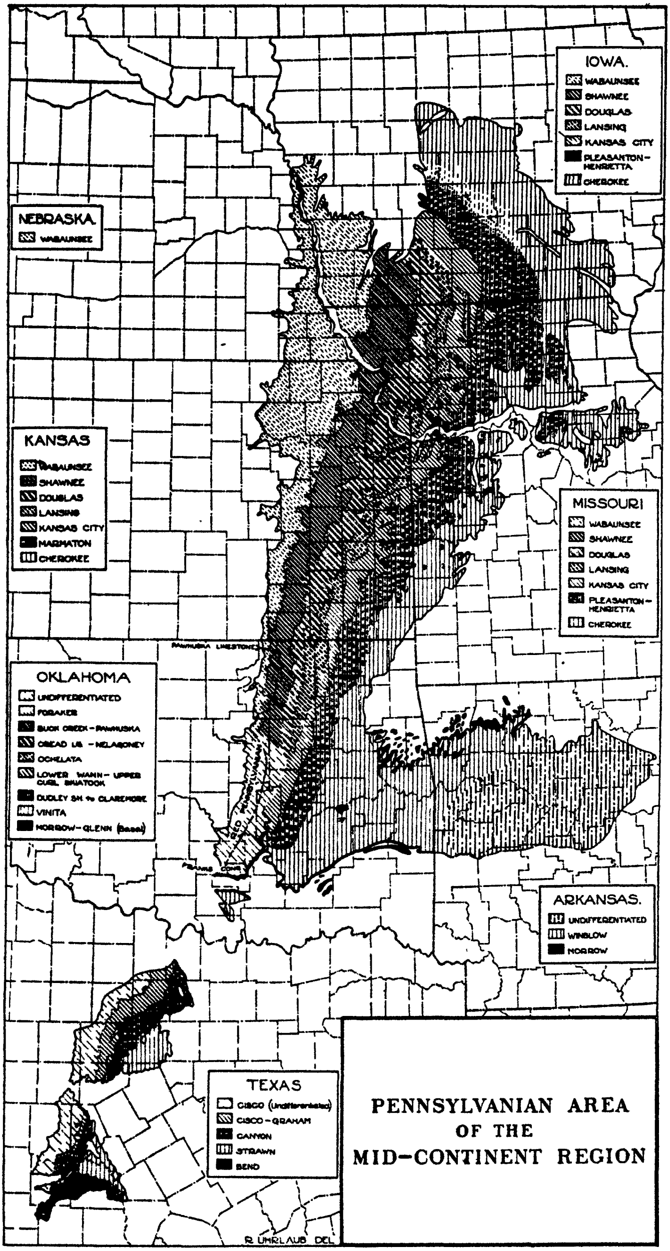

Fig. 63.—Pennsylvanian area of the Mid-continent region. (*After Moore, Bull.* A.A.P.G., **5**, 47.)

the actual thickening of individual members in the section as they are traced south. All these factors make correlation very difficult. An idea of the divergence of strata is conveyed in

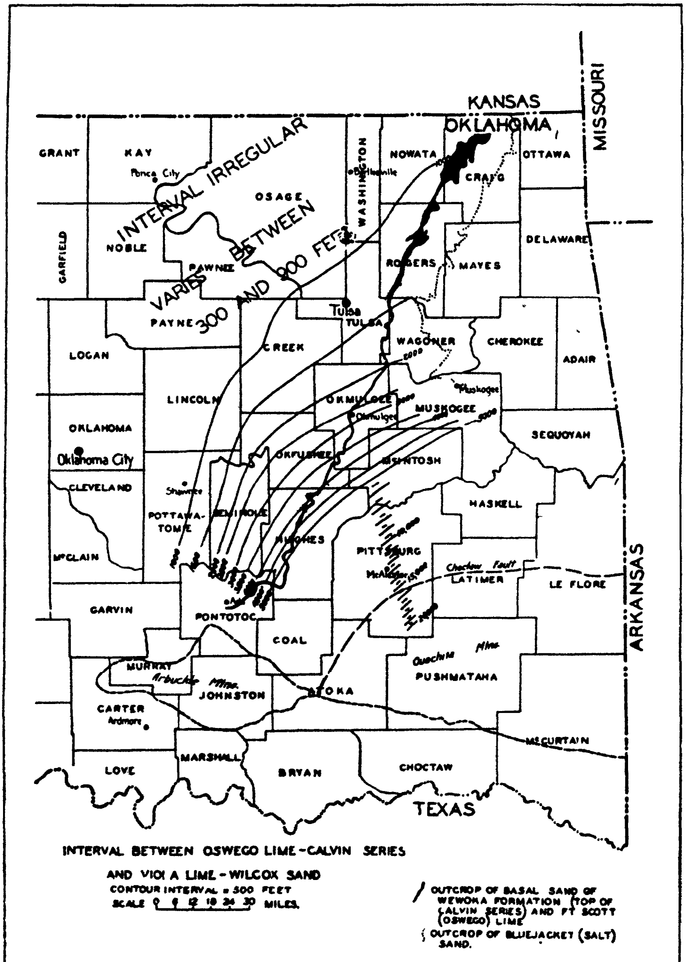

FIG. 64.—Isopachous map showing the interval between the Calvin-Ft. Scott horizon (Pennsylvanian) and the Viola "Wilcox" (Ordovician). The contour interval is 500 feet. (*After Levorsen, Bull.* A.A.P.G., **11**, 666.)

Fig. 64, which shows the interval between the limestone at the base of the Marmaton formation and the Wilcox sand of Ordovician age. This interval includes several unconformities but most of the divergence is due to the Pennsylvanian strata. The

divergence varies from 300 feet in Osage County to 20,000 feet in the southeastern part of Oklahoma. A north and south line from the state boundary on the north to McIntosh County on the south shows a divergence of 4,000 feet. (See Fig. 99, p. 251.)

Producing Horizons.—In the area under discussion in this chapter the horizons which produce oil and gas occur in all parts of the stratigraphic section from the lowest Ordovician to the highest Pennsylvanian, and even into the Permian formations. The most important producing horizons are the Siliceous lime (Arbuckle limestone) and Wilcox sand in the Ordovician system; and the Dutcher series of sands, the Bartlesville sands, and the Calvin series of sands in the Pennsylvanian system. In Kansas, at least 30 individual sands have been named and found to produce important quantities of oil or gas locally, and in Oklahoma at least 36 sands have been found similarly important. The greater number in both states appear in the Pennsylvanian system with the Cherokee formation showing the highest percentage and perhaps the most valuable. Tables on pages 203 and 253 will convey an idea of the vertical distribution and the character of these sands.

Relation of Production to Structure.—An impartial analysis of the peculiarities of oil occurrence in the whole producing territory involved in this province leads to the conclusion that structure has had a profound influence on the migration and accumulation of oil, but that other conditions have had an influence which locally makes the relationship very obscure. The most potent structural element in this province is the Prairie Plains monocline. The prevailing dip of the surface rocks and of the subsurface rocks, in a direction toward the west and at varying rates, has tended to cause the oil and gas to migrate toward the east. On its long, or sometimes short, journey, it was intercepted by high and large domes or anticlines in the western portion of the province, and in the eastern portion of the province by much smaller and lower structures. In fact, in the eastern portion of the area, pinching sands and differential porosity seem to outweigh the importance of structure entirely. Some exceptions to these broad generalizations must be made. For instance, it seems to be a fact that the production from the Wilcox horizon, which is now so great as to constitute more than half of Oklahoma's total production, occurs under definite structures. These structures look like small domes on

the producing horizon and are reflected to the surface very often in the form of small noses or plunging anticlines.

KANSAS

The search for oil in Kansas started soon after the first well was drilled near Titusville by Colonel Drake. In fact, within 6 months of the time that famous well was completed three wells were started in Miami County, near Paola. As had been the case in the east, so here also, seepages led to the location of the first tests. In earlier days, a surveyor by the name of Searle had noted oil exudations on the Wea and other streams to the east of Paola. One of the tests was drilled to a depth of 100 feet. On account of the Civil War, however, operations were entirely suspended and were not resumed until about 1870. Gas was found and a little oil was also discovered. The excitement spread to Linn, Johnson, and Wyandotte counties, and later to the southwest through Neodesha, Independance, and Coffeyville. By 1895, large areas had been tested and the production of both oil and gas was large.

The discovery of oil at El Dorado reads like a romance, revealing not a little of tragedy and missed opportunity. The state geologist of Kansas and his son located the dome at El Dorado and recommended a drilling site near the apex of the dome where the town had bought a block of acreage. By the irony of fate, the first well drilled in 1914 was dry and the acreage was turned over to the Empire Oil and Gas Company, for a small sum and the promise to drill three other wells. Later on, some of the phenomenal gushers of the Trapshooter lease were drilled almost within a stone's throw of the original test well. A few of these gushers produced over 10,000 barrels per day when they came in.

In 1923, oil was found in northwestern Russell County, fully 135 miles away from the other oil pools of the state. Since that time, ten other pools have been discovered in the western part of the state and a number of gas pools and oil pools have been located between the Russell County area and the eastern producing district.

The map (Fig. 65) shows the area in Kansas in which oil and gas have been found up to date. It will be noted that the pools arrange themselves into zones or districts running nearly northeast and southwest, and that five such districts may be defined at the present time. These districts are (beginning in

the east) first, the shallow sand zone running from Kansas City and Johnson County to Montgomery and Chatauqua; second, the Greenwood to Cowley County zone in which somewhat peculiar conditions obtain; third, the Chase, Butler, and Sumner counties zone; fourth, the broad zone including McPherson, Rice, Reno to Barber counties; and fifth, the zone including

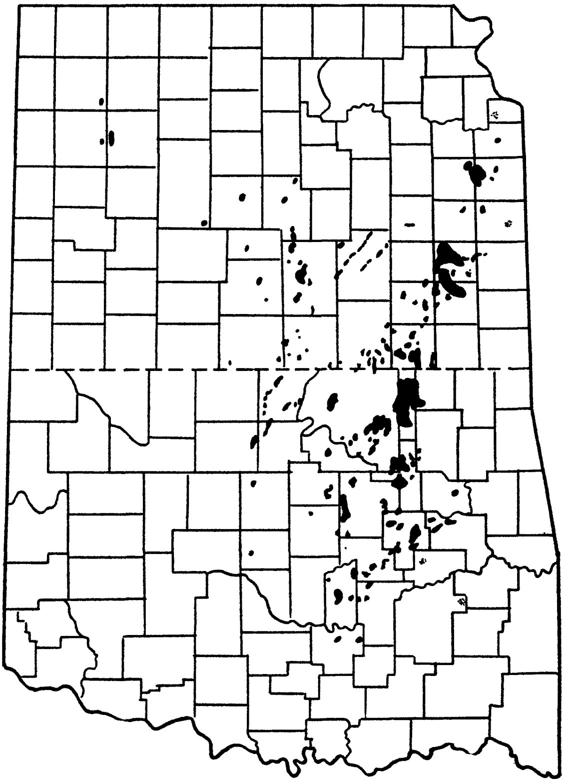

FIG. 65.—Map of Kansas and northern Oklahoma showing distribution of oil and gas fields.

Rooks and Russell counties. As is shown later, each of these zones has some characteristics of structure or sand conditions which set it off from the others. The area in which oil and gas pools occur is 250 miles wide and 125 miles long.

Tectonic Elements.—Among the tectonic elements which should be considered in connection with the oil fields of Kansas, the Prairie Plains monocline takes first place. The name of

"Prairie Plains monocline" was first suggested by G. I. Adams[1] and has been used by a good many writers. It refers to the west and northwest dipping strata which lie in Kansas and northern Oklahoma. The rate of dip on the monocline is about 25 to 30 feet per mile. On the eastern border of the monocline, the Ozark dome and its extensions north and south have exerted some influence on it; essentially, however, the monocline must be interpreted as the result of a slightly greater tendency to subsidence in the area west of the Ozark dome than in the region of the dome itself. The regional dip is most noticeable on the Mississippian and Pennsylvanian rocks. In the Permian rocks, the dip has a tendency to flatten considerably, and in the younger rocks the dip is from west to east.

Next in importance to the Prairie Plains monocline is the tectonic element usually referred to as the "granite ridge." It is a narrow zone of uparching in the older Paleozoic rocks and the underlying granite which extends from Nemaha County in the northern part of the state to western Cowley County in the southern part of Kansas. Figure 59 shows that the ridge lies highest at the north where the granite was reached at a depth of 500 feet from the surface. It dips to the south so that at the southern end the granite lies at depths of 3,000 feet or more below the surface (2,600 feet below sea level). Figure 59 also shows the wells which have reached the granite on both sides of the ridge. One well located in the Cheyenne bottoms of Barton County went almost 300 feet into the pre-Cambrian. The material encountered on the ridge, as well as most of the material found off the ridge, is either granite or gneiss. Some wells encountered thin sheets of schist before going into granite. This schist seems to occupy depressions in the granite, as indicated by the Breitkreuz well in the northwestern part of Greenwood County.

History of the Granite Ridge.—The geological history of the granite ridge is very interesting. From evidence furnished by deep wells on the ridge and on the flanks the following series of events may be assumed: In upper Ordovician time (or perhaps at the close of the period) faulting took place along a line, coinciding very nearly with the steep east dips shown in Fig. 59. Movement along this great rift took place probably at intervals extending through Silurian and Devonian times. In Missis-

[1] Adams, G. I., *Science*, p. 508, Mar. 30, 1900.

sippian time the high level of the ocean waters (of which there is evidence in other parts of the United States) encroached upon portions of the ridge which by this time had been worn down to a very regular surface with some saddles, peaks, and ridges. The Chattanooga shale of early Mississippian age was laid down over a wider area than was the limestone which came later. Both are found in the holes along the ridge and over

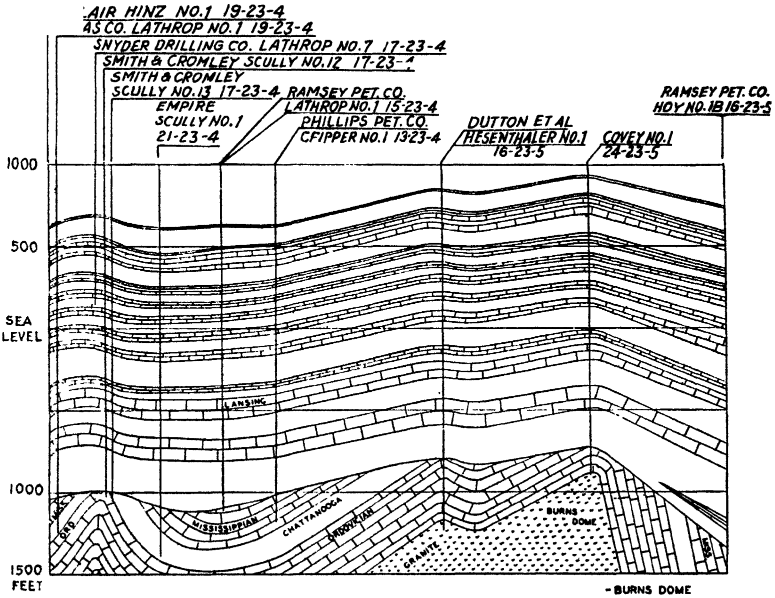

FIG. 66.—East-west cross-section across the granite ridge from the Elbing field to the Burns dome. (*After Thomas*, A.A.P.G. *Symposium*, **1**, 67.)

nearly the whole ridge farther south. Renewed faulting in late Mississippian time left the ridge exposed to erosion during Maramec and Chester epochs. The soil formed during this erosion interval produced red rock and chert as is even now the case where limestones suffer deep weathering. Finally, sometime during the Pennsylvanian period, ocean waters again encroached upon the land mass by overlap in such a way that a much more complete section is found to the south than to the north, where the ridge stood higher. Hence the Cherokee (which is so essential as an original source of oil in Kansas) was not deposited to any extent north of T. 23 S. nor on the west flank. In Fig. 66, the granite ridge is shown by the position

of Burns dome which is one of the prominent hills on the buried mountain range. It will be noticed that the Mississippian rocks are missing and the thin uppermost Cherokee or the Marmaton rests directly upon the Ordovician limestones (see also Figs. 58 and 62, pp. 169 and 173).

The granite ridge is reflected in the surface rocks of Permian age. The sharp reversal of the regional dip was noted by the

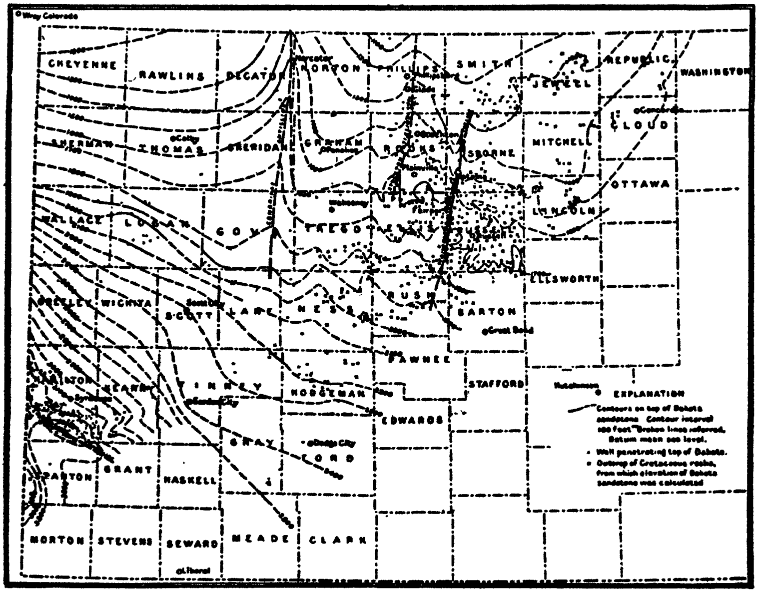

FIG. 67.—Reconnaissance map of western Kansas, showing structure of Dakota sandstone. (*After Bass, Kans. St. Geol. Survey Bull.* 13, p. 141.)

early workers in stratigraphic geology (Prosser and Beede at Elmdale, etc.) and later other places of east dip were found, finally establishing a pronounced, indeed the most pronounced, zone of reverse dips in Kansas. The maps published by Fath[1] in connection with his study of the El Dorado region show as much as 140 feet of reverse dip at places (as at Oil Hill and Boyer Dome).

A number of other lines of anticlinal folding have been described in Kansas. One of these is the Beaumont anticline, shown in Fig. 76, p. 208, which can be traced from Cambridge in T. 31 S., R. 7 E., at least as far as Eureka in T. 25 S., R. 11 E.

[1] FATH (see Bibliography).

and perhaps as far as the Virgil pool in northeastern Greenwood County—a distance of over 75 miles. The reverse dip on this structure is as much as 90 feet in places, and probably indicates a fault or several faults parallel to the Nemaha fault.

Figure 67 shows some of the more prominent anticlines of western Kansas. The Fairport-Natoma anticline has been traced from Rush to Smith County. Production has been found on this structure. The Stockton anticline is also well marked in the Dakota sandstone. The Cambridge anticline has been traced from eastern Gove County through Sheridan and Decatur counties into Nebraska. In the southwestern part of the state is the Syracuse dome in southern Hamilton County.

Besides the large structural features there are innumerable small structural modifications of the Prairie Plains monocline, such as noses or "plunging anticlines," terraces, and small domes. As a rule, they do not exceed 5 square miles in area and are arranged more or less parallel to the strike of the strata. An unusually large one is the Rose dome in southern Woodson County, which is nearly 10 square miles in area and has a closure of at least 80 feet[1] and in which the subsurface structure on the Oswego lime is very similar to the surface structure. Seven tests placed on all sides of the dome and drilled to the Mississippi lime were unsuccessful in finding commercial quantities of oil or gas.

Subsurface Structures.—Some of the subsurface structures are as important as, if not more important than, the structures which show in the surface rocks. The most prominent of these so far discovered in Kansas is the *Chautauqua arch,* first described and delineated in Oklahoma by Luther White.[2] This arch extends over into Kansas and may be said to affect the three southernmost rows of counties in southeast Kansas. It was produced at the same time that the main Ozark dome was produced, in fact, it forms a part of that structural element. By differential subsidence the areas toward central Kansas and central Oklahoma were dropped lower relatively than southern Missouri. Consequently, in the central part of the dome and on the flanks, reaching as far west as Cowley County, Kansas, only the massive limestones of lower and middle Ordovician

[1] Ley, Henry A., Subsurface observations in southeast Kansas, *Bull. A.A.P.G.*, 8, 450, 1924.

[2] *Okla. Geol. Survey Bull.* 40, B, 1926.

time were laid down. Farther west, successively younger strata overlap these limestones as the deeper parts of the basins are approached. One of these basins has its axis in central Sumner County, the other one is the Salina basin. It means that in southeast Kansas the drill will encounter no Devonian or Silurian strata after passing through the Chattanooga shale, but will enter instead the Jefferson City limestone (of the Missouri section) or the Arbuckle limestone (of the Oklahoma section), which are of Beekmantown or lower Ordovician age.

Another similar arch or very broad anticline was produced by similar differential subsidence in western Kansas. It has not been described in the literature but is known to include portions of Ellsworth, Rice, Stafford, and Pawnee counties, which form the southeastern edge of this plunging structure and the outer limit of the lower Ordovician limestones. North and west of these counties the structure rises, and successively lower portions of the Arbuckle limestone are encountered below the Mississippian rocks, or Pennsylvanian rocks, where the former are missing. This arch has been called the "Barton arch" and it is separated from the Chautauqua arch by a low saddle. The Arkansas River, flowing through Reno and Sedgewick, very nearly marks the axis of this saddle. On the saddle, the Kimmswick-Plattin limestones (Viola (?) lime of Oklahoma) appear beneath the Mississippian rocks (see Fig. 96, p. 244).

Important Basins.—The complimentary tectonic elements for the arches described are the *Salina basin*, the *east Kansas basin*, and the basin beginning in Harper County. One of these basins has been very interestingly described by Barwick[1], as the Salina basin of north-central Kansas. Figure 59 (p. 171) shows the location of this basin as well as the Chautauqua arch, Barton arch, Nemaha granite ridge, and the *Abilene anticline*. Figures 60, 61 and 62 show three cross-sections indicating the structure of the rocks in the basin. The east Kansas basin has not been described, and, because most of the wells in that part of the state were drilled long ago when samples were not well kept, its exact configuration may not be known for some time. In the third basin, active exploration is going on at present and within a reasonable time accurate information as to its depth, shape, and size will be accessible.

[1] Barwick, John S. (see Bibliography at end of chapter).

Origin of Structural Features.—Anticlines were at one time thought to be caused by tangential pressure, or folding because of pressure. Recent experimentation and investigation have shown that other processes may produce the same result. The first, and perhaps most effective, cause for some of the structural conditions described above is *differential subsidence* of the sea bottom on which strata were accumulating. Secondly, Blackwelder has pointed out that *differential compaction* or uneven condensation, due to the difference in compression suffered by different kinds of rock under a load, may cause anticlines to form. Undoubtedly this has also been a factor in Kansas, but as Straub[1] points out, a careful quantitative determination on some of the Kansas domes and anticlines reveals that such compaction does not account for all the arching of the strata. A third process by which anticlines may come into being is by *unequal warping* of the sea bottom because of the strains and stresses induced by differential subsidence. This process has some features which are similar to the tangential pressure theory but differs in that the thrust is mostly in a vertical direction and the effects are much more local and restricted. Finally, Fath has developed the idea that anticlines on the surface may be due to faulting in more rigid rocks below; that *horizontal movements* in the *basement rocks* along lines of shear are transmitted to the overlying incompetent strata and produce on them faults and folds having a trend essentially parallel to the displacement below.[2] If the faulting in the basement rocks is more nearly vertical it will also be transmitted, but not necessarily to the surface. In other words a fault at depth passes into a fold nearer to the surface.

Stratigraphy.—The succession of rocks in Kansas is relatively simple in its broad aspects but complicated in small areas. Most of this complication arises because of the presence of two unconformities, the one below the Pennsylvanian rocks and the one below the Mississippian rocks. There are other unconformities in the section, but these two are the cause of the greatest amount of difficulty in correlation.

[1] Straub, Charles E., Effect of gravitational compaction on the structure of sedimentary rocks, *Bull.* A.A.P.G., **11**, 889, 1927.

[2] Fath, E. A., El Dorado oil and gas field, *Kans. St. Geol. Survey Bull.* 7, p. 151, 1921.

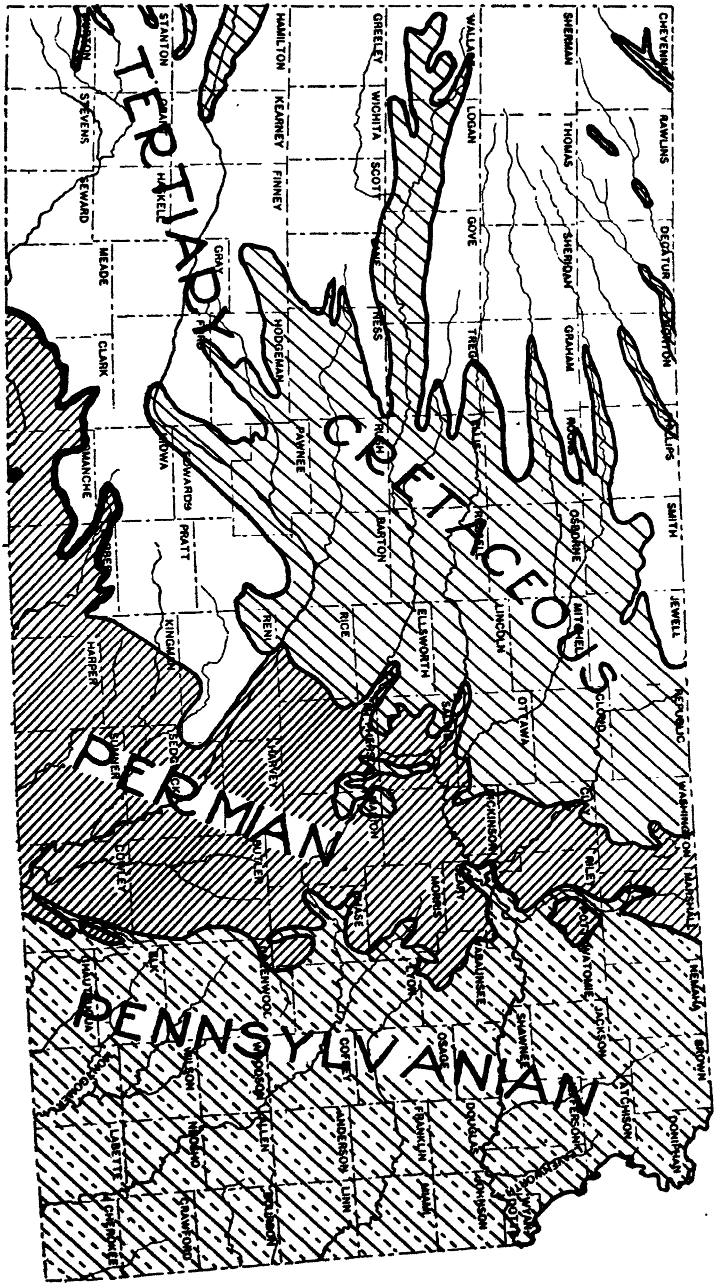

Fig. 68.—Geologic map of Kansas. (*After Moore, Kans. St. Geol. Survey Bull.* 13, p. 10.)

The map (Fig. 68) shows the areal geology of Kansas. It will be noted that the Paleozoic rocks crop out in nearly parallel bands in the eastern part of the state, but the younger rocks make a much more complicated pattern in the western part. The reason for this will be pointed out presently. Mississippian rocks occupy only a small portion of the state; Pennsylvanian rocks occupy a belt somewhat over 100 miles wide; Permian rocks form a belt narrow at the north, but somewhat wider toward the south. The Comanchean system crops out only in a very narrow zone in Barber, Comanche, Clark, and Meade counties. The Cretaceous and Tertiary rocks occupy the rest of the state. Beginning with the youngest system, they may be briefly described as follows:

Tertiary Rocks.—The Tertiary rocks are spread out in a relatively thin sheet over most of western Kansas. They produce the characteristic plain extending from central Colorado to central Kansas which (with its continuations into adjacent states) is often referred to as the Great Plains or High Plains. The name "Ogalalla formation" has been given to these rocks from the characteristic outcrops at the town of that name in southwestern Nebraska. The Ogalalla consists of sands and gravels, and in places, these materials are cemented together by calcium carbonate to form what is called "mortar beds," but, as a rule, the sand and gravel are only loosely cemented. The individual grains in the Ogalalla consist of crystalline rock fragments, for the most part, quartz pebbles being the commonest constituent, with fragments of granite, porphyry, syenite, and dark-colored igneous rocks making up the remainder. The well-rounded nature of the material indicates that it has been carried a long distance from its source and that it has probably been carried by streams. In thickness it varies from zero to more than 300 feet, but 175 feet is a very common average. It may be seen from this, that the streams which have cut through it from the west to east had no difficulty in penetrating it and exposing the Cretaceous beneath. This may be seen from the map (Fig. 68) especially along the Smoky Hill River. Fossil remains found in the Ogalalla have been referred to the Miocene and Pliocene epochs of the Tertiary period.

Cretaceous Rocks.—The Cretaceous rocks cover about 25,000 square miles of western Kansas. They are exposed in long, narrow bands where stream dissection has cut out the overlying

sheet of Tertiary material. The generalized section (Fig. 69) shows the thickness and character of the Cretaceous and Comanchean rocks. The total thickness probably does not exceed 1,300 feet, and in most places it is considerably less, yet the thickness of individual members of the section is remarkably uniform. It will be noted that the Cretaceous proper is made up of shale, limestone, and sandstone, in the order named. The shale is partly sandy and partly clayey or calcareous, and the limestone is inclined to be chalky. The shales are mostly dark colored and somewhat bituminous with occasional thin beds of lignite. The limestones are mostly soft and non-resistant to erosion, often grading into pure chalk. Concretions of flint, chert, etc. are rather common at certain horizons. Most of the sandstone occurs at the base of the Cretaceous and forms part of the *Dakota* formation. It is coarse grained, loosely cemented, massively bedded, and characterized by very much cross-bedding. The predominance of iron oxide as a cementing material gives it a rusty color on the outcrop. Its high porosity makes it a good reservoir for water, oil, and gas.

The regional dip in the Cretaceous rocks appears to be to the northeast and at a very gentle angle of about 6 feet to the mile. Structural modifications in these rocks have been found and described by several writers. Many large domes have been outlined, but by most geologists these structures have been given only slight attention because of the possibility of their near surface origin. In other words, the chalk beds in the system and the gypsum beds as well as the salt beds in the underlying Permian are so susceptible to removal by circulating ground water that the cavities thus created will produce many local and erratic rearrangements of the surface beds. Nevertheless, recent discoveries in western Kansas indicate that some reliance may be placed on Cretaceous structure. The Cretaceous of Kansas has been divided into the formations and members shown in Fig. 69.

Comanchean Rocks.—A glance at the map (Fig. 68) will show that the *Comanchean* rocks crop out in a very limited area in the southern part of the state. The system is thin in Kansas, only 300 feet being present. At the base is a very much cross-bedded sandstone resting unconformably upon the Permian red beds which has been called the "Cheyenne sandstone," from its occurrence at Cheyenne rock near Belvidere in Barber County.

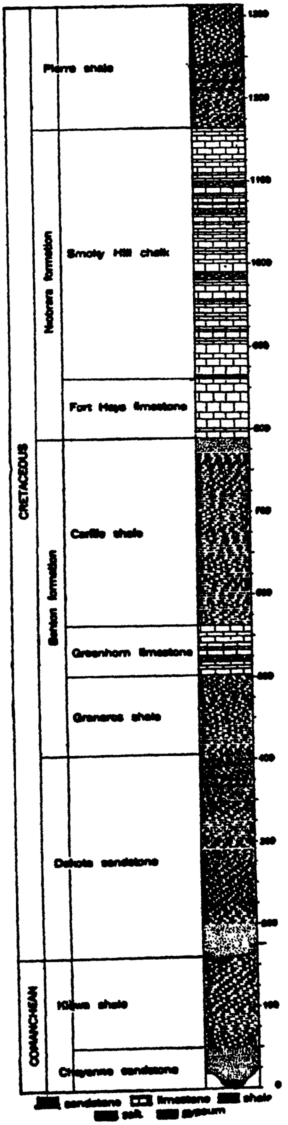

FIG. 69.

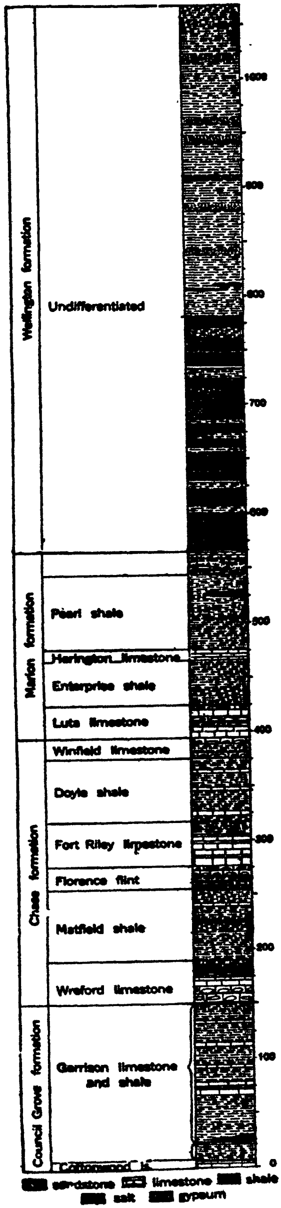

FIG. 70.

FIG. 69.—Generalized section of the Comanchean and Cretaceous systems in Kansas. (*After Moore, Kans. St. Geol. Survey Bull.* 13.)

FIG. 70.—Generalized section of the Big Blue series of the Permian system in Kansas. (*After Moore, Kans. St. Geol. Survey Bull.* 13, p. 19.)

This sandstone varies from 40 to 70 feet in thickness (see Fig. 69). Above the sandstone, a shelly, fossiliferous limestone appears in some places which was called by Cragin the "Champion shell bed," and in which fossils of Fredericksburg age were found. The bed is very thin, not exceeding a few feet, and is succeeded by a rather thick body of dark-colored shale above, which has been called the "Kiowa shale." It is about 130 feet thick. The shale is mostly calcareous, very uniform in character throughout and contains many fossils.

Permian Rocks.—The Permian rocks of Kansas may be subdivided into two series on the basis of lithology and color. The upper is called the *Cimarron* and is distinguished by its predominant red or pink color and its composition of sandy shale and sandstones. The lower has been called the *Big Blue* from its typical development along the stream by that name in Marshall, Riley, and Pottawatomie counties. It consists of limestones and shales alternating at small intervals, especially toward the base of the section. Figures 70 and 71 will give a picture of the character, composition, and thickness of these two series. It will be noted that the Cimarron series contains some salt and gypsum, especially in the central part of the section. Otherwise, it consists chiefly

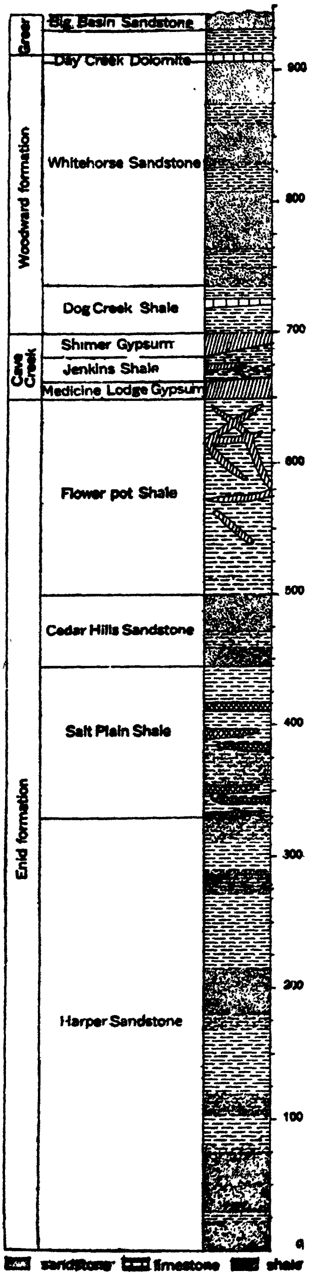

FIG. 71.

FIG. 71.—Generalized section of the Cimarron series of the Permian system in Kansas. (*After Moore, Kans. St. Geol. Survey Bull.* 13, p. 19.)

of bright-red shales and sandstones. The thickness is approximately 1,200 feet. The Big Blue series resembles the Pennsylvanian very closely in the lower half (as far up as the Pearl shale), on account of the character of the limestones, which are white and thin bedded. It is, therefore, well adapted for making surface structure maps. The upper half of the section is quite different. It consists of shales with thin sheets of gypsum and in some places thick lenses of salt. The color of these shales is mostly red or green. Occasional thin dolomitic bands serve to mark off mapable units, although it is difficult to follow these thin layers because the rocks do not crop out very extensively. Nevertheless, it is remarkable how persistent such thin markers are and over how great an area they have been found. This applies also to the sandstones and thin white bands in the Cimarron which have also been traced by geologists over very considerable distances.

As to origin, it may be concluded that the Cimarron series and the *Wellington* formation of the Big Blue series are largely continental deposits formed in a region where great aridity prevailed, and mostly in temporary lakes. The lower portion of the Big Blue series appears to have been laid down in marine waters.

The base of the Permian has been placed at the base of the Cottonwood, by the U. S. Geological Survey. By others it has been variously placed higher and lower since there is no sharp line of demarkation either lithologically or paleontologically. The Wreford, at the base of the Chase formation, is preferred by some.[1] The Neva limestone a short distance below the Cottonwood limestone would be the most convenient base, as this layer can be traced farther into Oklahoma than any other of the key horizons. The dip of the Permian strata varies considerably. The Big Blue series dips westward at a rate similar to that of the underlying Pennsylvanian system. The Cimarron series appears to lie at much flatter angles, lying nearly horizontally over considerable areas. In the southern portion of the outcrop area, the dip seems to be directed toward the south at a low angle suggesting a possible basin similar to the Anadarko basin in southern Oklahoma.

Pennsylvanian Rocks.—The Pennsylvanian rocks of Kansas have probably been more thoroughly described and mapped in

[1] See WILLIS, *Prof. Paper* 71.

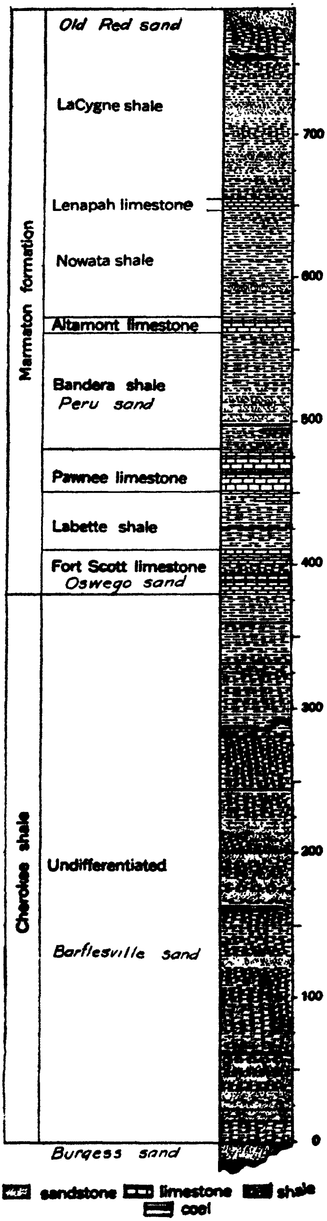

FIG. 72.—Generalized section of the Des Moines series of the Pennsylvanian of Kansas. (*After Moore, Bull.* 13, p. 15.)

detail than has any other portion of the stratigraphic section. This is due to the fact that the system consists of a series of relatively thin limestones separated by thin zones of shale and occasional sandstones. Twenty of these limestones have received names and has been traced along the strike from north to south nearly across the width of the state. They lend themselves beautifully to plane table mapping of surface structure, and it is partly for that reason that there is such complete information about their distribution. In a general way, the limestones are thickest at the north end of the outcrop and gradually become thinner toward the south, though a few exceptions seem to thicken toward the south. Relatively few pass into Oklahoma and very few pass beyond the Arkansas River in that state. The thickness of the whole Pennsylvanian system is about 3,000 feet in the northern and about 3,500 feet in the southern part of the state. Some variation is introduced by the unconformity at the top of the underlying Mississippian which makes the thickness considerably less in local restricted areas. Toward the west, the thickness diminishes also, being but 1,300 feet in Russell County, 2,000 feet in Clark County, and only 1,400 feet in Hamilton County.

Figures 72, 73 and 74 show the general character and thickness of the individual members of the Pennsylvanian system in Kansas. It will

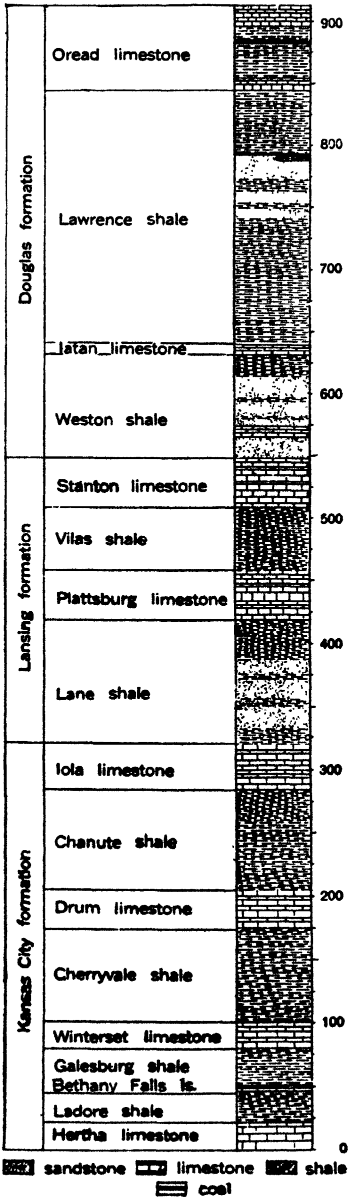

FIG. 73.

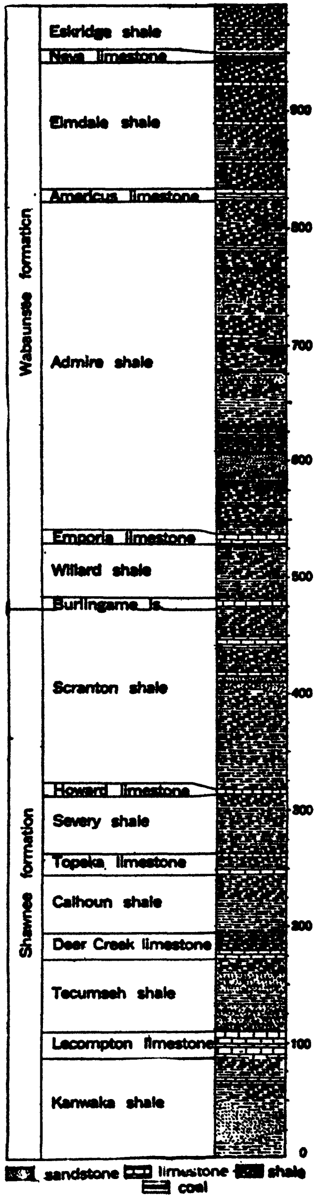

FIG. 74.

FIG. 73.—Generalized section of the lower part of the Missouri series of the Pennsylvanian of Kansas. (*After Moore.*)

FIG. 74.—Generalized section of the upper portion of the Missouri series of the Pennsylvanian system of Kansas. (*After Moore.*)

be noted that the most abundant kind of rock is shale with limestone in second, and sandstone in third place. Near the base some coal beds appear. The lowest formation, the Cherokee, is the most interesting one in the section, for it contains the most prolific sands as well as being the probable source rocks for most of the oil and gas found in the state. It consists of dark bituminous shale and thin, interbedded sandstones, the most prominent one of which has been called the "Bartlesville sand" (or the Blue jacket sandstone on the outcrop in Oklahoma). The Cherokee is very uneven in thickness and distribution. It is thick in the east Kansas basin and also thick toward the southern portion of the state. North and west of certain points, it has not been found at all, which indicates that it was laid down in a transgressing sea on a rather irregular Mississippian surface. Furthermore, during Cherokee time the sea seems to have had oscillations so that there is evidence of interformational unconformities. After the beginning of the Marmaton stage, the water of the epeiric sea seems to have been deeper and more stable, for the members of the section above that horizon appear pretty regularly all over the state, although in a few places even a considerable part of the Marmaton is missing. For subsurface mapping and correlation, the limestone at the base of the Marmaton, called the "Ft. Scott" by the geologists and the "Oswego" by the drillers, is the most reliable datum plane. Next in importance is the thick mass of limestones which constitutes the Kansas City and Lansing formations and their interbedded shales. The limestones frequently take precedence over the shales and in the western part of the state eliminate the shales entirely. At the top of this limestone zone oil is frequently found.

The dip of the Pennsylvanian rocks is mostly about 40 feet to the mile toward the west in southeastern Kansas and somewhat less farther west—perhaps 25 to 30 feet on the average. The lower rocks dip at a greater angle, and in southeastern Kansas the average is about 75 feet to the mile toward the west. Many wrinkles of the Pennsylvanian surface modify the amount and direction locally.

Mississippian Rocks.—Rocks of Mississippian age crop out in the southeastern corner of the state only. Here the dip away from the Ozark dome brings some of these rocks to the surface over a small area. They have been traced beneath the surface by means of many deep wells drilled during the last 40 years.

There are many abrupt changes in the surface configuration of the limestone, however, for sometimes wells find a drop of 150 feet within a quarter of a mile between two locations. The Longton anticline is a good illustration of this condition. This anticline is really an elongated anticlinal hill in the Mississippian surface, located in Elk and Chautauqua counties, at the top of which the section of rock is less than one-third as thick as it is on the flanks and the adjacent basins, showing that pre-Cherokee erosion was very great. On this buried structure, one of the great gas fields of the state is located, the gas coming from the truncated top of the Mississippian rocks.

The Mississippian system is represented in Kansas by a very massive cherty limestone from 300 to 350 feet thick, corresponding to the Burlington and Keokuk formations of the Osage series in Missouri, thus placing it in the lower third of the Mississippian system. Below the Osage in Missouri lies the Kinderhook formation, which has been subdivided by Shepard[1] in southwest Missouri into the following members beginning at the base: A black fissile shale lies at the base (being about 50 feet thick) and is called the "Eureka" or "Noel" shale. Above this lies a thin grey limestone, called the "King member;" and above that is another limestone (about 8 feet thick) called the "Sac limestone member." A sandstone 4 feet in thickness overlies the Sac and is called the "Phelps member," above which the Louisiana limestone, Hannibal shales, and Chouteau limestone appear in regular succession, similar to northeast Missouri. In the well records of Kansas, no such fine distinction into members is possible. All the above members with the exception of the lowest are included in what is usually called the "Mississippi lime"; and the lowest member—the black shale (Eureka or Noel)—is called the "Chattanooga shale." It will be recalled that the Chattanooga shale is a very persistent horizon in the oil fields of more eastern provinces where it is probably of Devonian age in most cases, but undoubtedly of Mississippian age in some cases, and possibly the upper portion is always of Mississippian age. Thus, the correlation is very close and, above all, very convenient. The name "Chattanooga" will probably be used in the future, as it has in the past, by geologists working in Kansas. In parts of southern Kansas, geologists working on

[1] Shepard, E. M., Geology of Greene County, Missouri, *Mo. Geol. Survey*, **12** (1st. Ser.), 67.

subsurface problems distinguish some patches of grey, green, and red shales with thin limestones above. These, no doubt, correspond to the members of the Missouri sections described above. When traced to the north, these grey, green, and red shales thicken rapidly until they occupy the entire thickness of 150 feet usually occupied by the black shales.

The thick limestone mass above the Chattanooga or Kinderhook shale zone has been called the "Boone limestone." Buchanan states[1] that the Boone formation contains late Burlington fossils near the base and in the upper portions a Keokuk and early Warsaw fauna. Above the Boone limestone another limestone zone is found in Oklahoma (and to some extent in southern Kansas), which is usually referred to as the "black Mississippian limestone." This limestone is called the "Mayes limestone" from outcrops in northeastern Oklahoma near Mayes. It has a thickness of from 3 to 100 feet and lies above the Chattanooga shale in parts of north-central Oklahoma where the Boone is missing. In the literature on Kansas geology no mention is made of this formation.

The Boone limestone (or "Mississippi Lime" as it is usually called) is a very excellent key horizon for subsurface correlation in Kansas. Also the black shale zone below it—the Chattanooga —is a very reliable marker.

Pre-Chattanooga Formations.—In pre-Chattanooga time, a great deal of what is now Kansas was a land area and, therefore, subject to erosion. Some portions of the land area had been land since middle Ordovician time, while other less extensive areas were submerged during a part of the intervening interval. Some Devonian, some Silurian, much upper Ordovician, and large areas of middle Ordovician rocks may be found under the Chattanooga shale. These areas have been described in a general way in the preceding pages and the following pages will therefore be limited to a discussion of the nature and thickness of the rocks.

Devonian and Silurian Rocks.—No rocks of Devonian or Silurian age crop out within the limits of the state of Kansas. The nearest area where they may be studied is in adjacent parts of Missouri. In west-central Missouri, no lower Devonian has been found, but some middle Devonian has been described

[1] BUCHANAN, G. S., Distribution and correlation of the Mississippian of Oklahoma, *Bull.* A.A.P.G., **11**, 1314, 1927.

from there. It is called the "Cooper limestone," and consists of about 30 feet of fine-grained, compact, light grey, sparingly fossiliferous limestone. Upon this limestone were deposited (after an interval of erosion) other beds of limestone called the "Callaway limestone" of upper Devonian age. These limestones

GENERALIZED STRATIGRAPHIC SECTION FOR KANSAS

System	Series	Formation	Thickness feet	Description	Correlation
Tertiary	Mio-Pliocene	Ogalalla		Sand and gravel	
Cretaceous	Montana	Pierre	125	Shale	
	Colorado	Niobrara	350	Limestone, chalk, and shale	
		Benton	400	Shale and limestone	
	Dakota	Dakota	225	Sandstone and shale	
Comanchean		Kiowa	125	Shale, dark colored	
		Cheyenne	50	Sandstone, cross-bedded	
Permian	Cimarron	Greer	50	Sandstone and shale, red	
		Woodward	200	Sandstone and shale, red	
		Cave Creek	50	Gypsum and red shale	
		Enid	650	Sandstone and shale, red, gypsum	
	Big Blue	Wellington	500	Red and green shale, salt, gypsum	
		Marion	150	Limestone and shale	
		Chase	225	Limestone and shale	
		Council Grove		Limestone and shale	
Pennsylvanian	Missouri	Wabaunsee	500	Limestone and shale	
		Shawnee	500	Shale and limestone, some sandstone	
		Douglas	450	Shale and limestone	
		Lansing	225	Limestone and shale	
		Kansas City	300	Limestone and shale	
	Des Moines	Marmaton	400	Limestone, shale and sandstone	
		Cherokee	400	Shale, sandstone, coal, limestone	
Mississippian	Osage	Boone	350	Limestone, cherty	Mississippian lime
	Kinderhook	Chattanooga	100	Shale mostly black	Skelton in part
Siluro-Devonian		Hunton(?)	400	Limestone	Younkin
Ordovician	Cincinnati	Sylvan	100	Shale	Maquoketa
	Mohawk	Viola	135	Limestone	Urshel and Plattin-Kimmswick.
	Buffalo	St. Peter	70	Sandstone and shale	Wilcox and Tyner.
Canad. Ozark		Siliceous lime		Limestone 900 feet	Arbuckle and Jefferson City, etc.
Pre-Cambrian		Schist			
		Granite			

appear to have been deposited in a sea advancing from the north.

Silurian rocks are not present in the same part of the state, and, in fact, are rare in any part of the state except possibly along the eastern side of the Ozark dome. Interesting in this connection is the finding by Ulrich[1] of Silurian rocks of Niagaran age in Holt County near Forest City, at a depth of 2,400 feet. Just north of the Missouri line in Iowa near Bedford, Norton[2] reports 575 feet of limestone, dolomite, and shale reached at a depth of 1,825 feet.

In Kansas, rocks of Devonian and also some of possible Silurian age have been described by Barwick from the Salina basin. He describes a zone of white to grey dolomitic limestone which is locally interbedded with lenses of sand. He gives the name "Younkin formation" to this limestone, after the name of a well in Clay County (where the horizon was found at a depth of 2,194 to 2,520 feet). He inclines to the belief that these rocks are of the same age as the rocks described above, that is, of middle Silurian and middle and upper Devonian age. Rocks in a similar stratigraphic position in Oklahoma are called "Hunton formation," but this formation includes rocks of *lower Silurian and lower Devonian* age. In Clay and Riley counties, the Younkin formation attains a thickness of over 400 feet.

Ordovician Rocks.—In adjacent parts of Missouri, rocks of Ordovician age are very widespread and may be studied in the area of the Ozark dome. They consist there in descending order of the following formations, on p. 199.

In Kansas, rocks which are of Ordovician age have been described by Barwick from the Salina basin. His unit No. 4 (which he calls the *Engle shale*) consists typically of light-colored, fine-grained shales generally with a bluish-grey or greenish-grey cast. In places, it contains small amounts of dolomitic material or quartz sand. It has a thickness of 60 to 100 feet. This shale zone is probably equivalent to the *Maquoketa* of Missouri and Iowa and the *Sylvan* shale of Oklahoma.

Below the Engle shale lies the *Urshel limestone*, unit No. 5 of Barwick. It is a dolomitic limestone, white to brown in

[1] ULRICH, E. O., The revision of the Paleozoic systems, *Bull.* Geol. Survey Am., 22, 1911.

[2] NORTON, W. H., Underground water resources of Iowa, *Water Supply Paper, U. S. Geol. Survey* 293, p. 965, 1921.

System	Series	Formation	Character
Ordovician	Cincinnati	Maquoketa	Impure shaly limestone
		Fernvale	Limestone carrying Richmond fossils
	Mohawkian	Kimmswick	Coarsely crystalline, non-cherty limestone
		Decorah	Blue and green shale, some limestone
		Plattin	Limestone, some chert, massive
	Buffalo (Chazyan)	Joachim	Limestone, fine-grained grey to buff dolomite
		St. Peter	Sandstone, massive white friable, well-rounded and etched sands grains
	Canadian	Jefferson City	Dolomite with chert and thin seams of sandstone 500 to 600 feet thick in west Missouri (Benton and Newton counties) adjacent to Kansas
		Roubidoux	Sandstone, dolomite, and chert. Extremely variable in composition and thickness; 60 to 250 feet
Cambrian	Ozarkian	Gasconade	Dolomite, 100 to 300 feet thick, granular, sugary
		Proctor	Dolomite, 60 feet thick very little chert
		Eminence	Dolomite, cherty, 200 feet thick
		Potosi	Dolomite, siliceous, cherty, and drusy

color, commonly cherty, and ranges from a few to 135 feet in thickness. It correlates approximately with the *Viola* limestone of Oklahoma and the Plattin, Decorah, and Kimmswick formations of Missouri. This limestone is the main producing horizon in the Florence-Urshel pool of Marion County and important also at Peabody, Elbing, Covert-Sellers, and at Leon in Butler County. In some well samples, fossils of Decorah age have been found in green shales below this limestone which makes it appear that the Urshel limestone is the equivalent of the Kimmswick limestone only.

Below the Viola limestone of Kansas, a sandstone is found in well records which has been called the "St. Peter sandstone."

This horizon is very widespread and (if the sandstone called by this name in so many parts of the country is the same stratigraphic horizon) is a very convenient marker for subsurface correlation over very wide areas. The typical St. Peter sandstone of Wisconsin and Minnesota is a somewhat peculiar sandstone, in that the grains are better rounded than usual and somewhat etched as if by wind action. Sandstones or sandy phases of magnesian limestones have been correlated with this horizon in Ohio, Kentucky, Illinois, Indiana, Iowa, Missouri, Arkansas, and Oklahoma. In Kansas, Barwick has described the *St. Peter* (unit No. 6) from the Salina basin as a rounded to angular quartz sandstone with fairly persistent lenses of green shale. It ranges in thickness from 40 to 120 feet with an average of about 70 feet, and corresponds to the Wilcox sand of Oklahoma, as indicated in the following correlation chart:

Pre-Mississippian Correlation Chart for Kansas[1]

Standard	Kansas	Oklahoma (North)	Missouri	Iowa
Devonian	Limestone		Cooper Bailey	Devonian
Niagaran		St. Clair limestone		Gower Hopkinton
			Alexandrian (?)	Alexandrian
Richmond	Maquoketa (?)	Sylvan (?)	Maquoketa shale	Maquoketa
	?	Fernvale	Fernvale	Fernvale
Trenton	Viola: Kimmswick limestone	Upper Tyner limestone	Kimmswick limestone	Galena
Upper Black River	Viola: Decorah shale	Middle Tyner	Decorah shale	Decorah
Lower Black River	Viola: Plattin limestone	Lower Tyner shale and sandstone	Plattin lime stone	Platteville
			Joachim limestone	Glenwood
Blount	St. Peter	Wilcox	St. Peter	St. Peter
Middle Chazy Lower Chazy	Simpson sandstone and shale	?	Everton	

[1] Based chiefly on chart by Bush, F. A., and Miss Fanny Edson, *Bull.* A.A.P.G., May, 1929.

PRE-MISSISSIPPIAN CORRELATION CHART FOR KANSAS[1] (*Continued*)

Standard	Kansas	Oklahoma (North)	Missouri	Iowa
Canadian	Siliceous lime	Cotter Dolomite	Powell Cotter Jefferson City	Shakopee
Ozarkian	Siliceous lime stone		Roubidoux	New Richmond
			Gasconade	Oneota
			Eminence	Jordan
			Potosi	St. Lawrence
St. Croixan	Basal sand		Davis Bonneterre Lamotte	Franconia
Pre-Cambrian	Granite	Granite	Granite	

[1] Based chiefly on chart by BUSH, F. A., and MISS FANNY EDSON, *Bull.* A.A.P.G., May, 1929.

This horizon is perhaps the most important producing horizon in Oklahoma and may become the same in Kansas. It is found immediately below the black shale in southern Butler, northwestern Cowley and eastern Sumner counties. Again, on the southeast flank of the Barton arch, it occurs below the black shale in Ellsworth, Rice, Reno, Stafford, Pratt, Edwards, and Kiowa counties. In the saddle between the Chautauqua and Barton arches it occurs below the Viola limestone in the counties bordering on Sedgwick County.

In Missouri, a great series of dolomites and limestones occurs below the St. Peter. In the Ozark dome adjacent to Kansas the Jefferson City, Gasconade, and Eminence dolomites with the interbedded sand lenses called "Roubidoux" and "Gunter" appear in the section. We are therefore justified in assuming that the limestone which is encountered in the deeper wells drilled in southeastern Kansas on the Chautauqua arch, and which is usually referred to as the "siliceous lime," is one of these formations. Perhaps it is mostly the Jefferson City dolomite.

In Oklahoma, the middle and lower Ordovician part of the section is composed of a very massive dolomitic limestone fully 6,000 feet thick in the Arbuckle Mountains. The name of the formation is the "Arbuckle limestone," and this name is used by geologists working in Oklahoma for the limestone encountered on the Chautauqua arch in northeastern Oklahoma. The

Arbuckle limestone may therefore be correlated, for practical purposes, with the Jefferson City limestone and the Siliceous lime. This is the lowest horizon in which oil or gas have been encountered in Kansas and it is at present an important source. It is of Canadian age which means lower Ordovician according to the older classification.

Producing Horizons.—In Kansas the various horizons which have or are producing important quantities of oil or gas none are younger than the Wabaunsee formation of Pennsylvanian age. Most of the pay zones are members of the Pennsylvanian system. A few belong to older systems, including the Canadian. The youngest producing horizon is the shallow oil zone at ElDorado, etc., which occurs in the Admire shale. This horizon is also responsible for considerable gas in Cowley County at the present time. Some oil is found at about the 900-foot level in the vicinity of El Dorado in the top of the Shawnee formation and the Scranton shale member. An important producing gas zone is also found in the Calhoun shale of the Shawnee formations and another one in the Tecumseh shale of the same formation. The Elgin sandstone (Hoover sand) which lies in the Kanwaka shale member at the base of the Shawnee formation is not important, but does produce in a few scattered localities. In the Douglass formation, two productive zones are known. One of these lies in the Lawrence shale near the top and the other lies in the Weston shale near the base of the formation. The latter is the Boyer sand of the El Dorado region.

At the base of the Douglass, and probably occupying what should be the horizon of the Stanton limestone, is a sandstone which must be classed as one of the most important producing horizons. It is called the "Stalnaker sand" in the Oxford pool of eastern Sumner County (on the trend of the Nemaha granite ridge). It also produces oil in the western part of the state in the pools of Russell and Rooks counties where it was first called the Oswald lime. Subsequently, lower pay zones were found in the Fairport field and other fields of Russell County in the limestone of Lansing and Kansas City age, but the name "Oswald lime" should be retained for the first porous zone found in the Stanton limestone. All the sands mentioned previously were true sands, but this producing horizon is a limestone.

At the top of the Kansas City formation there is a producing zone which has been called the "Encill sand." It is chiefly

productive in Elk County. The Drum limestone of the same formation contains the Stokes sand which produces oil at El Dorado and vicinity. Near the base of the Kansas City in the Ladore shale member lies the Layton sand, which is a good producer in Oklahoma but has only slight importance in this state. At the base of the formation in the Hertha limestone lies the gas sand of Elk County.

In the Marmaton formation are found a number of important oil horizons. The Old Red sand produces in Chautauqua and Elk counties. The Peru sand and the Weiser sand also produce in the same part of the state. The Oswego lime at the base of the formation produces chiefly in Elk and Chautauqua counties.

The Cherokee formation contains the most valuable sands found up to the present time. In the upper portion of the formation, the shoestring sands occur (of Anderson and Linn counties). Near the center, the sands called "Bartlesville" (and sometimes "Burbank") appear. For a long time the Bartlesville sands produced the greater part of the oil of the state, and they still produce a large share of it. The Burgess sand seems to be a sand which fills depressions in the underlying Mississippi lime but it may be placed in the basal part of the Cherokee formation.

For purposes of reference and to furnish a rapid survey of the producing horizons in Kansas the following table has been compiled. The most important ones are starred:

TABLE OF PRODUCING HORIZONS IN KANSAS

System	Formation	Member	Horizon and where productive
Pennsylvanian	Wabaunsee	Eskridge shale Neva Elmdale shale Americus	
		Admire shale	550-foot and 660-foot sands at El Dorado Gas sand, Cowley County
		Emporia Willard shale Burlingame	
	Shawnee	Scranton shale	990-foot gas sand at El Dorado
		Howard limestone	Highest "pay" at Oxford
		Severy shale Topeka limestone	Good shows at Oxford, Churchill, etc.
		Calhoun shale	1,125-foot gas sand at El Dorado, etc.
		Deer Creek Tecumseh shale	1,200-foot gas sand at El Dorado, etc.
		Lecompton Kanwaka	Elgin and Hoover sands

TABLE OF PRODUCING HORIZONS IN KANSAS (*Continued*)

System	Formation	Member	Horizon and where productive
Pennsylvanian	Douglass	Oread Lawrence	1,475-foot gas sand at El Dorado, etc.
		Iatan Weston shale	Boyer oil sand at El Dorado, etc.
	Lansing	*Stanton limestone	*Oswald lime in Russell County pools, etc. *Stalnaker sand at Oxford, etc.
		Vilas shale Plattsburg Lane shale	Lower "pays" at Fairport and Russell counties
	Kansas City	Iola limestone Chanute shale Drum limestone	Encill sand of Elk County Stokes oil sand at El Dorado, etc.
		Cherryvale Winterset Galesburg Bethany Falls Ladore shale	Layton sand
		Hertha limestone	Gas sand of Elk County
	Marmaton	Dudley shale Lenapah limestone *Nowata shale	Old Red sand of Chautauqua and Elk counties *Peru sand of Montgomery, Elk, and Chautauqua counties
		Altamont Bandera shale	Weiser sand of Montgomery and Chautauqua counties
		Pawnee Labette shale	Peru sand in some places in southeast Kansas
		Fort Scott limestone	Oswego lime of Elk, Chautauqua, Wilson, etc.
	Cherokee		Shoestring sands of Linn, Anderson County *Bartlesville sand of Greenwood, Butler, Cowley, etc. Trends of Greenwood County, etc.
			Various horizons in Bourbon, Butler, Elk, Franklin Labette, Lyon, Miami, and Neosho counties
			Burgess sand in Chautauqua, Elk, and Montgomery
	Pennsylvanian basal conglomerate of varying age—*Welch chert in part. Gorham sand (Western Kansas)		
Mississippian	Osage	Boone	*Mississippi lime in south central Kansas. Chautauqua, Elk, Greenwood, and Montgomery *Welch chert in part
	Kinderhook	Chattanooga	First break, basal sand, Misener of Oklahoma
Ordovician	Viola lime		*Viola lime or second break in lime of south-central Kansas. Viola production in Marion County, etc. Sometimes called "Leon lime."
	St. Peter or Wilcox		*Wilcox sand. Sumner County, Sedgwick, etc. Stapleton zone of El Dorado in part.
	Arbuckle		*Siliceous lime of granite ridge and Cowley County Stapleton zone of El Dorado in part. Produces in Graham pool and in Elk County

An interesting horizon is the Pennsylvanian basal conglomerate. This horizon is not a stratigraphic level but occurs at any place in the Pennsylvanian series which happens to overlie the eroded surface of the underlying older strata. The best discussion of this horizon may be found in a paper by Barwick previously referred to on the Salina basin to which a discussion

by various geologists is attached. The first, and perhaps typical, locality at which the horizon was found is in the Welch farm well in southeastern Rice County, on account of which it is called the "Welch chert." The name is misleading for it does not always consist of chert nor does it contain much chert except in certain areas. Where it overlies Mississippian limestone, it may consist of nearly pure chert fragments sometimes 150 feet thick. Barwick believes this is residual chert resulting from the leaching out of the limestone by ground water. In other areas, where the basal conglomerate does not overlie the Boone formation it may consist of quartz fragments (and indeed any kind of clastic material) and would then appear to be a true basal conglomerate (Gorham sand). It has been found in that condition in Barton County and on the flanks of the Barton arch, in general. This horizon now produces oil in southeastern Rice County and in several pools of Russell and other western counties.

The top of the Mississippi lime is often porous and therefore is capable of serving as a reservoir for oil and gas. No great quantities have been found in Kansas. Still fair amounts have been obtained in eastern Greenwood, in Montgomery, Elk, and Chautauqua counties. The Longton gas field is one of the fields which has important production in this horizon. Where the Mississippian limestone has been deeply leached during the erosion interval between Boone and Pennsylvanian times residual chert has accumulated which may then be the same as the Welch chert. Within the limestone, occasional porous streaks are found that produce oil or gas, but these are not persistent nor important. At the base of the black Chattanooga shale sandy patches are found of small extent. These sandy patches are thought by Luther White to be sand dune areas which were submerged by the widespread seas of early Mississippian time and are called "Misener sand" in Oklahoma. Production from this horizon has so far been of no consequence in Kansas.

Ordovician Horizons.—In recent years, deeper drilling has been carried on in Kansas with the result that some very prolific horizons have been found below the Mississippian rocks in the rocks of Ordovician age. The uppermost horizon of importance is the Viola lime or Urshel lime of Barwick. This zone of porous limestone has been found productive in the fields of Marion and Sedgwick counties which lie on the west flank of the Nemaha

granite ridge, and the Peabody, Elbing, Covert-Sellers, and Florence Urshel pools. It also produces in the Leon district of eastern Butler County and at some points in the El Dorado district.

The Wilcox sand or St. Peter sandstone will also become a very important producer in Kansas for it is now the most prolific horizon in Oklahoma and there is no good reason why it should change its character radically in crossing the boundary. It has been found productive in a small part of the Augusta-El

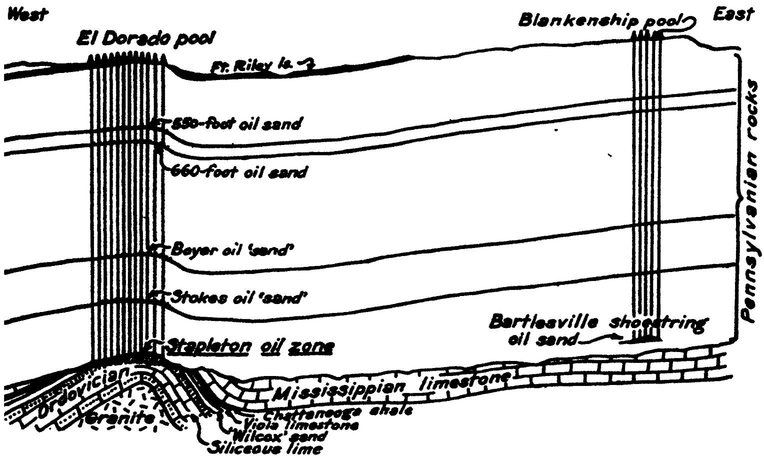

FIG. 75.—Cross-section of the El Dorado and Blankenship pools in Butler County Kansas. (*After Moore, Kans. St. Geol. Survey Bull.* 13, p. 85.)

Dorado district and in Sumner, Sedgwick and McPherson Counties. In the Augusta district, Fath describes the lowest producing zone as the Stapleton zone and correctly interpreted it as a zone produced by erosion of truncated edges of Ordovician rocks. The Wilcox sand is thus truncated in a narrow belt in southern Butler and northern Cowley counties and has yielded good wells in that belt on favorable structure (see Fig. 75).

The Siliceous lime where it has been exposed to erosion and acquired a porous condition is also an important producing zone. This is true in portions of the El Dorado area where it forms a part of the Stapelton zone. It is also true in western Cowley county in the Graham pool (see Fig. 75). In southeastern Elk County in the Arbuckle pool production was found at a depth and in such a stratigraphic position that it was called Wilcox

sand production. This area was later shown to be lacking the Wilcox horizon and it is now known to be the siliceous lime. It seems altogether reasonable to assume that more oil will be found in the siliceous lime in the counties of southeastern Kansas.

Relation of Production to Structure.—In the easternmost zone of producing territory of Kansas, stretching from Johnson to Chautauqua counties, the relation between production and structure is obscure. If surface structure alone is used production is found on anticlines, domes, terraces, synclines, and basins. Hence, while it may be true that the chances for good production are better on the first three types of structure enumerated, it does not follow that there is a causal relationship. Subsurface structure on producing levels has not been published for any considerable areas, hence it is difficult to state whether there is a close relation or not. The surface structure, however, is very likely to reflect the subsurface structure, and inasmuch as no very close correspondence is observable in the case of the surface the same conclusion holds for the subsurface. In explaining the occurrence of oil and gas in this zone, it seems that the patchy character of the sands is more important than is structure.

In the second zone of producing territory extending from northeastern Greenwood County through eastern Cowley County there are some very interesting structural conditions. Prospecting according to the old anticlinal theory (in Greenwood County, especially) led to a grand series of dry holes. A well placed high on structure could be expected to come in high and dry. Fortunately, other wells were drilled in the county on synclines and other unfavorable structure and these wells were, in part, successful. In this way, the Sallyards pool in T. 25 S., R. 8 E. was discovered, production being found not far above the Mississippi limestone in a sand body having the approximate position of the Bartlesville sand. Further testing developed a pronounced tendency for the good wells to line up on a trend. Subsequently, the trend was extended by finding other pools along the same line and in 1926 the pools of the county looked about as they are shown on the map, Fig. 76. The trend from the Madison pool to the Sallyards pool is probably the longest trend found to date and it is nearly 50 miles long. Some wells on this trend came in for 1,200 barrels flush production and many were rated at 500 to 700 barrels.

A very critical analysis of all structural features and possible modes of origin of the sand body in these trends was published

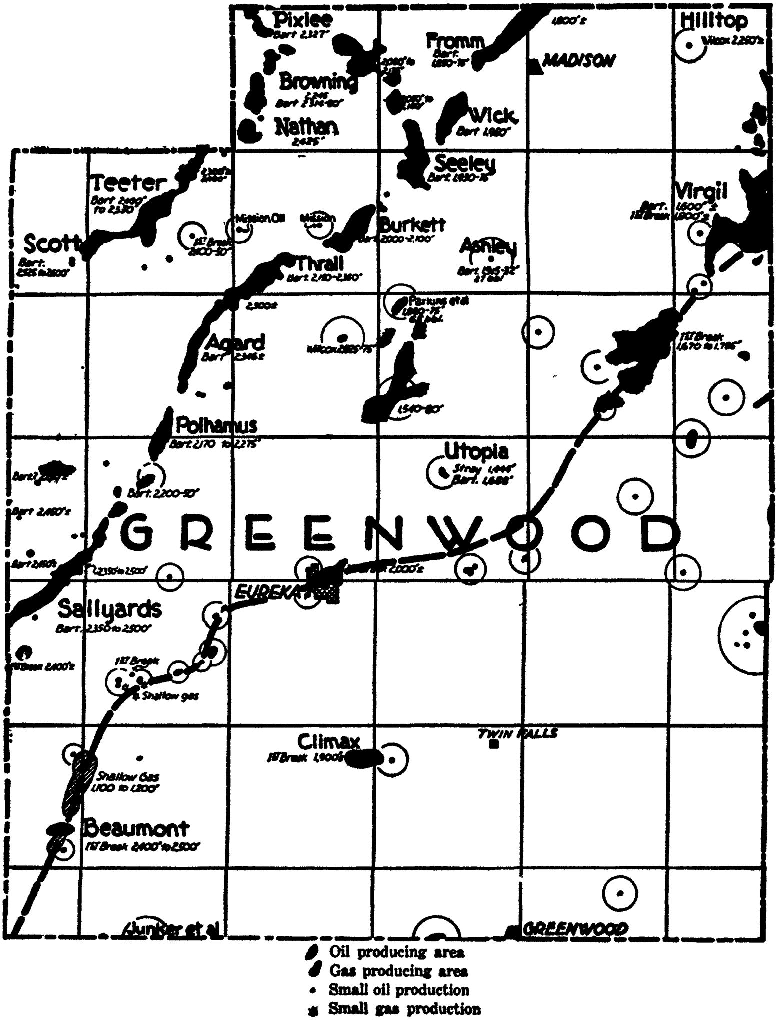

FIG. 76.—Map of Greenwood County showing the Sallyards-Madison trend, the Teeter trend, and the Beaumont anticline. (*After Moore, Kans. St. Geol. Survey Bull.* 13, p. 101.)

by Cadman.[1] He states that the sand body occurs in a more or less continuous long narrow strip, that it has a variable

[1] CADMAN, W. K., The Golden Lanes of Greenwood County, Kansas, *Bull.* A.A.P.G., **11** (No. 11), 1151*ff.*, 1927.

thickness, variable texture, a complex and irregular bottom. It is bordered by shale walls which are in places very abrupt so that in extreme cases one well may have 100 feet of sand and the offset well none, while many wells show 10 to 50 feet of sand which are offsets of wells without sand. After considering all the evidence, he concludes that these deposits are due to the work of streams in a valley-flat environment; that structural geology is of no value in indicating the presence of the trends; and that the trends of Greenwood County are but a part of a much larger network of channels.

Shoestrings.—Perhaps the first geologist to describe such river-channel deposits is Rich.[1] He found what he calls "shoestring deposits" in Anderson and Linn counties in the easternmost zone of the producing territory. The Bush City string which is 11½ miles long fills a channel cut sharply to a depth of 50 feet in blue shale of Cherokee age. The sand body consists of black shale at base above which lies 20 feet of clean white sand, then shaly sand, and above that white talclike shale. In the sand body there are lenses of coarser material some of which appear on the outside of a bend close to the bank of the channel. The depth of the bottom of the sand varies from 640 feet at the east to 840 feet at the west. It is not related to surface structure, but trends easterly up the regional dip for 8 miles, rising 120 feet in that distance, then it turns northeastward trending along the strike for about 2 miles, from where it cuts diagonally down the regional dip thus forming a closed anticlinal trap which is not in any way related to local structure.

The Warrensburg and Moberly channels described by Hinds[2] are cut into the Pennsylvanian deposits of Missouri to a depth of over 200 feet. They were evidently very steep sided, 2 to 3 miles wide, very long, narrow and straight and had few tributaries. One of these channels was traced 50 and the other 40 miles and Hinds believes that the original length was much greater. These channels were formed a short time before deposition of the Kansas City formation began.

[1] RICH, JOHN L., "Shoestring sands of eastern Kansas, *Bull.* A.A.P.G., **7** (No. 2), 103*ff*. (1923); also **10**, 569, 1926.

[2] HINDS, HENRY, Unconformities in the Pennsylvanian, *Bull.* A.A.P.G., **10** (No. 12), 1303, 1926.

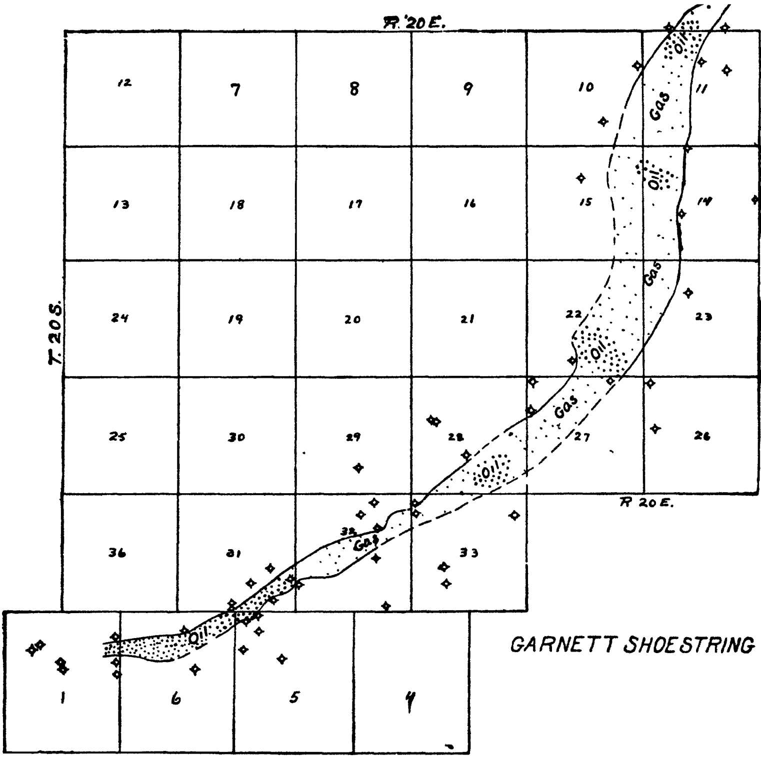

FIG. 77.—Garnett shoestring as of December, 1922. (*After Rich, Bull.* A.A.P.G., **7,** 106.)

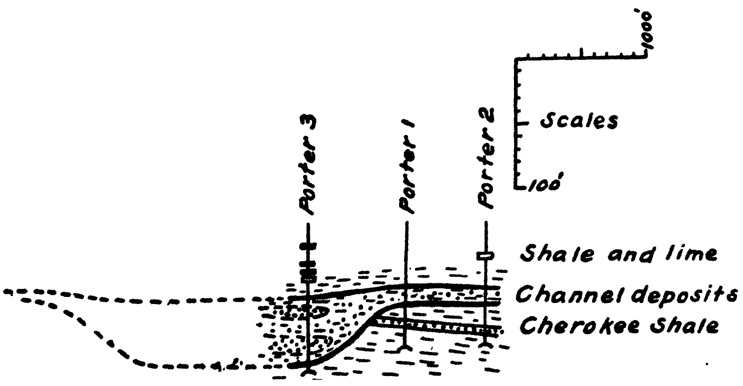

FIG. 78.—Typical cross-section of Bush City shoestring in S. 13, T. 21 S., R. 19 E. (*After Rich, Bull.* A.A.P.G., **10,** 571.)

In Greenwood County as the map (Fig. 76) shows there is a very pronounced anticlinal ridge over 70 miles long which is called the "Beaumont anticline." It has a reverse dip of nearly

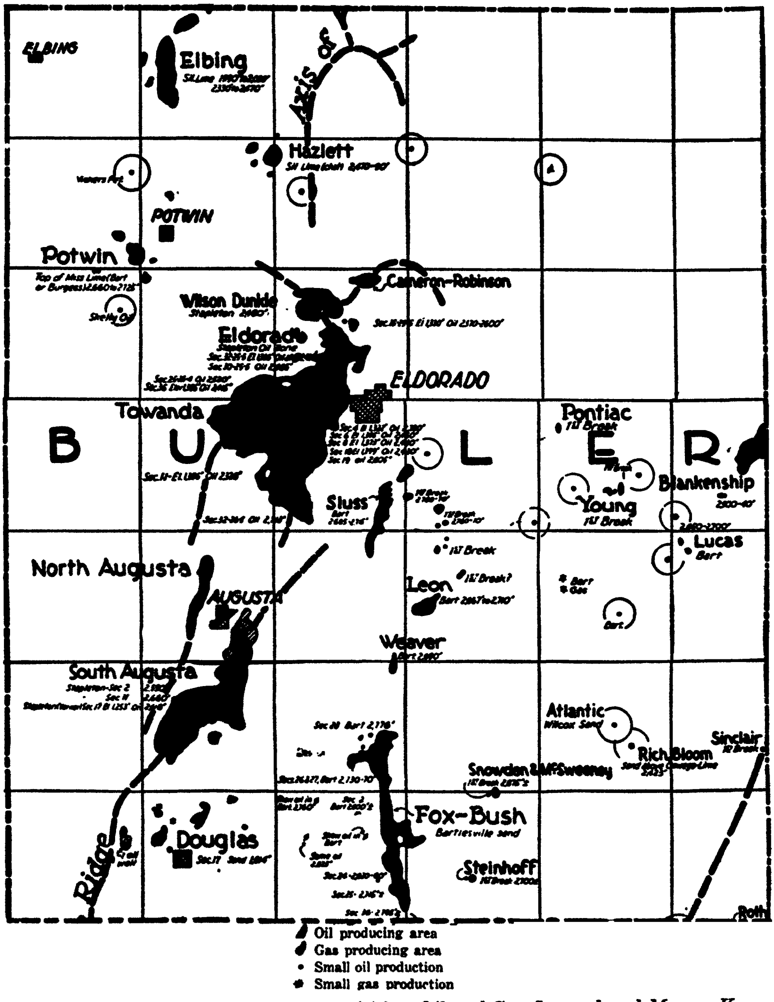

FIG. 79.—Map of Butler County. (*After Oil and Gas Journal and Moore, Kans. St. Geol. Survey Bull.* 13, p. 83.)

100 feet in places and is well marked all along its trend. If there is any relation between production and structure there should be a string of pools along this anticline. The pools are conspicuous by their absence. The reason for this condition

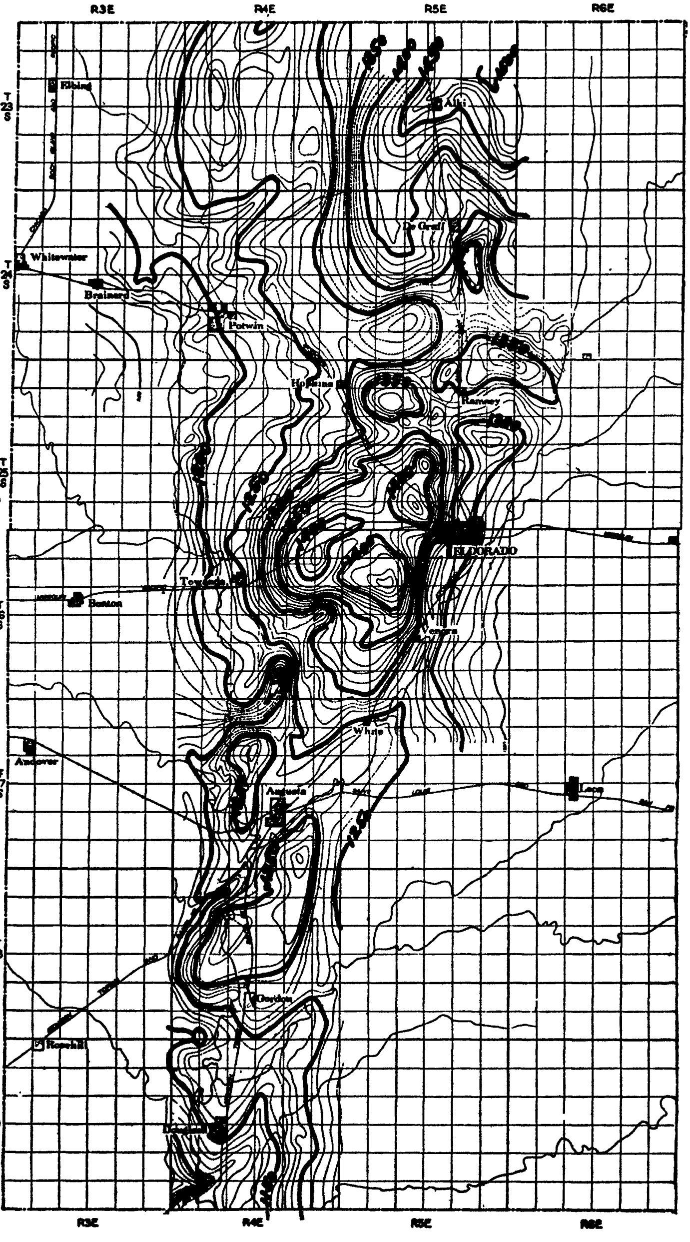

FIG. 80.—Structure map of El Dorado and Augusta oil fields. Contours on top of Ft. Riley limestone. (*After Moore, Kans. St. Geol. Survey Bull.* 13, p. 84.)

is the fact that the sands which might be a good reservoir for the oil or gas are missing. Some production has been found in the Virgil pool and few other pools along the trend. This production comes from the first break in the Mississippi lime.

The third zone of productive territory, extending from Chase County into eastern Sumner County, has very different characteristics from the other two zones. Here production and structure harmonize beautifully. Perhaps the most convincing illustration of the validity of the anticlinal theory might be found here. The outstanding pools of the Augusta-El Dorado district appear in this zone. More than 200,000,000 barrels of oil have been produced from the Butler County fields. In the year of peak production (1918) the El Dorado district alone produced nearly 30,000,000 barrels of oil. One of the largest wells ever drilled in this country, rated at 20,000 barrels per day, was brought in on the Trapshooter lease (NW. of S. 11, T. 26 S., R. 4 E.). The Shumway lease of the Gypsy Oil Company of 160 acres averaged over 50,000 barrels per acre.

Figure 79 shows the location of the El Dorado pool in central Butler County as well as the other pools of the same county. The rocks on the surface in this district belong to the lower Permian system, the Marion and Council Grove formations (see Fig. 70, p. 189). The field is located right on the axis of the Nemaha granite ridge and therefore a complete section of the Pennsylvanian is not present, the Cherokee and part of the Marmaton being absent. Below the Pennsylvanian the various members of the Ordovician system are found, eroded and truncated in such a way that narrow bands appear beneath the Pennsylvanian. The structure of the surface rocks is shown in Fig. 80, which represents the surface of the Ft. Riley limestone. The subsurface structure is shown in cross-section in Fig. 75, p. 206. It will be noted that there is a close correspondence between the two. A close correspondence is also to be noted between production and structure, for practically all the oil and gas is limited to the domes and the high saddles between the domes, while the synclines are dry. Oil sands occur at many horizons as may be seen by consulting the table of producing horizons on page 203. The 550- and 660-foot sands yield oil only. The sands at 900, 1,125, 1,200, 1,275, and 1,475 feet are gas sands. On the Oil Hill, Boyer and Shumway domes, four of these sands produce on each dome; on the Chesney dome, only the 1,275-foot

sand produces, and on the Wilson dome the 1,200- and 1,275-foot sands produce. All of these gas sands lie within the Shawnee and Douglass formations. The initial closed-rock pressure of these sands varied from 332 to 462 pounds. The Boyer oil sand lies near the base of the Douglass, and the Stokes oil sand lies in the Kansas City formation. Both of these are important producing zones, but do not begin to compare to the Stapleton zone in output. In the central part of the field, where it is structurally highest, the siliceous limestone underlies the Pennsylvanian and has accounted for most of the production. On the flanks and toward the south (Augusta) the Wilcox sand underlies the Pennsylvanian, and still farther out on the flanks the Viola (?) limestone carries some oil. The gravity of the oil ranges from 33 to 35°.

The fourth zone in the producing territory of Kansas extending from McPherson County to Barber County has only a few pools at the present time. It is the most recently explored zone and is still in its early stages of development. The pool at McPherson was discovered in 1926, gas being found in the top of the Mississippi limestone at a depth of 2,915 feet. Quite a number of wells were drilled during 1927 and early 1928. In June, 1928, the first oil well was brought in being capable of producing 500 barrels per day. In southeastern Rice County, the Welch chert type area, many large wells have been brought in, two of them rating above 1,200 barrels per day. The Welch chert, as was pointed out previously, occupies a position between the Pennsylvanian and Mississippian and may be assigned to either system in age, depending on its character. In the Rice County pool it seems to be of Mississippian age, consisting entirely of residual chert fragments. The producing zone lies at a depth of 3,352 to 4,404 feet. In Barber County, one gas well has been drilled in. It is located about 16 miles west of Hardtner and is the Alexander well drilled by the Shaffer Oil Company. The producing zone appears to be the top of the Mississippi limestone. Late in 1928, oil was discovered in Sedgwick County in thin limestones above the St. Peter.

The fifth zone is rather wide and takes in the rest of the state of Kansas. Practically every county in this zone has been tested by one or more wells and a fair number of them have been successful. In the southwestern portion, there are three gas wells located in Seward and Stevens counties. This gas appears

to be coming from the Permian system, possibly the Council Grove formation. If that is correct, it is the first Permian producing horizon discovered in Kansas. In the eastern part of Clark County, a gas field has been opened. The remaining wells are oil wells and are located in the northeastern part of the zone in Rooks and Russell counties. During 1929, oil was also found in Ellis, Trego, and Edwards counties.

Russell County.—Oil was discovered in Russell County in 1923, when the M. M. Valerius Company drilled in the discovery well, No. 1 Carrie Oswald. At that time this oil discovery was located at a distance of 150 miles from the nearest producing well (El Dorado). In this part of Kansas, Cretaceous rocks crop out at the surface and the regional dip is to the east. The Greenhorn limestone makes an excellent key horizon for working out the surface structure and below it lie the sandstones and shales of the Dakota and Comanchean down to a depth of 500 feet. At this point is an angular unconformity, for there the Permian red beds, with a west dip, underlie the Mesozoic rocks (Fig. 81). At the depth of 850 feet, a great bed of anhydrite is encountered 40 feet thick. From 1,200 to 1,500 feet much salt is found and below that red rock, anhydrite, shale, and dolomite to the base of the Permian at 2,100 feet. The upper part of the Pennsylvanian is blue shale with thin limestones carrying gas at 2,450 feet and 200 feet of massive limestone follows which is correlated with the Douglass formation of eastern Kansas. After a thin zone of variegated shale is passed, another massive limestone 240

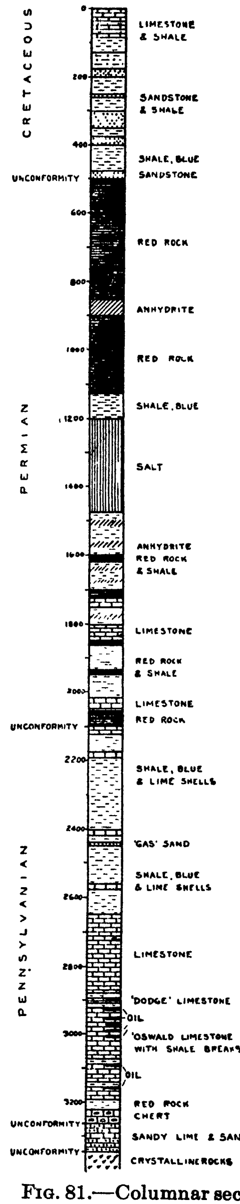

FIG. 81.—Columnar section of rocks for the Fairport oil field, Russell County. (*Allen and Valerius*, A.A.P.G. *Symposium*, 1.)

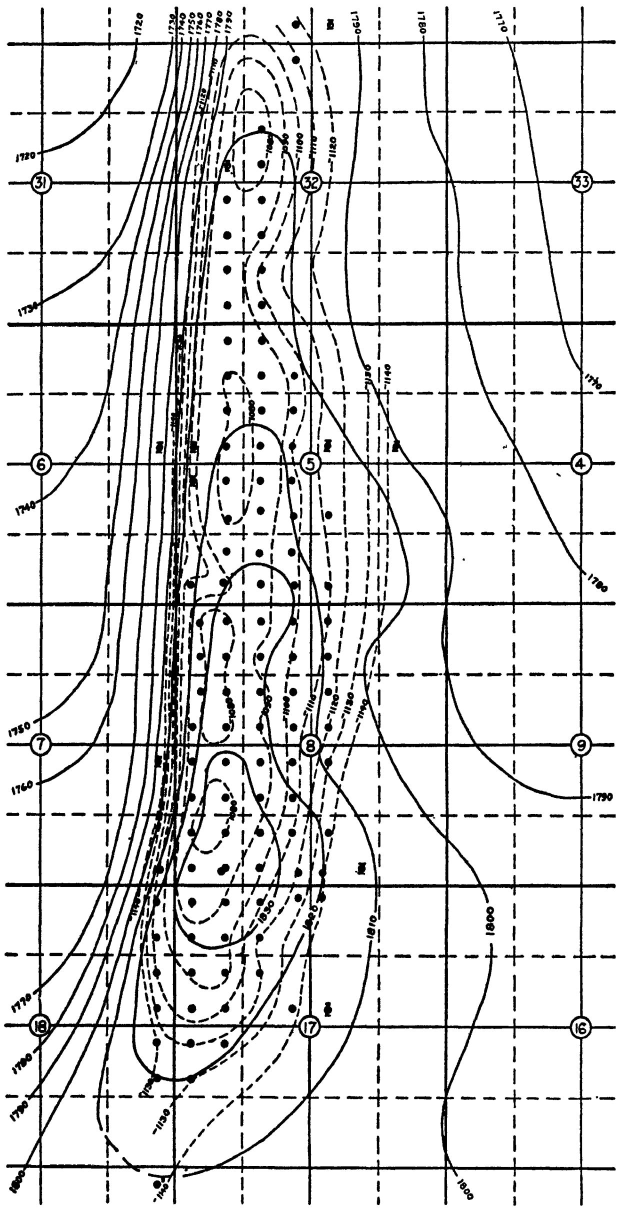

FIG. 82.—Map of Cretaceous and Pennsylvanian structure, Fairport oil field, Russell County, Kansas. (*After Allen*, A.A.P.G. *Symposium*, **1**.)

feet thick is encountered. This is the Lansing formation and contains at the top the producing horizon called the "Oswald lime." At the base of the Pennsylvanian (which lies just below the Lansing here) some red shale is found and a zone of chert, the basal Pennsylvanian conglomerate, also an oil horizon. Below that zone lie Ordovician rocks.

Much drilling since the first well came in has established the fact that the thick limestone in which the Oswald pay zone occurs may vary from 242 to 720 feet. The true Oswald pay zone lies from 10 to 15 feet in the lime. Below that at least nine other porous zones have been found in different wells, all of which may produce oil. Finally, large production has been found in the basal Pennsylvanian conglomerate (Gorham sand) which consists of red and green fragments of shale, chert, and limestone. Most of the oil has a gravity of 40°.

The structure at the surface in Cretaceous rocks reveals a dome on an elongated anticline which has a closure of 30 feet. The reverse dip on the west is sharp and amounts to 50 feet in one-half mile. On the east side of the structure, the dip averages 20 feet to the mile. The subsurface structure on top of the Pennsylvanian is very similar but accentuated. For instance, the steep west dip or reverse dip amounts to over 100 feet per mile and the east dip amounts to 60 feet per mile. The producing area on structure is 7 miles long and a little over 1 mile wide. (see Fig. 82). The production up to March, 1928 amounts to about 3,500,000 barrels of oil. The average production per acre is 3,500 barrels and the highest production per acre on the oldest lease is 6,400 barrels.

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NORTHERN OKLAHOMA

The oil and gas fields of northern Oklahoma are closely related to the fields of Kansas so that it is logical to treat both of them

in the same chapter. The reason for separating the fields of northern Oklahoma from those of southern Oklahoma is partly one of convenience and partly one of conditions founded on tectonic differences. As regards the former, everyone who has worked in the Oklahoma fields will admit that the fields of the state offer more complex conditions and a greater variety of confusing features to the student of oil occurrence than do the fields of any other state, with the possible exception of Texas. In order not to crowd too much into the picture, therefore, it seems advisable to describe the fields of the state in two sections. As regards tectonic differences, it will become apparent in the detailed study of northern Oklahoma that tectonic elements which controlled the accumulation of oil were different from those which were of importance in southern Oklahoma. Hence, a division is necessary on that fundamental basis (see Fig. 65, page 179).

The fields of northern Oklahoma include all fields lying between the state border on the north and the Canadian River on the south. The Canadian River bounds Cleveland, Pottawatomie, Seminole, northern Hughes, and McIntosh counties on the south. It forms a very convenient boundary line for our purpose. The oil and gas fields in this part of the state occupy a belt which is 125 miles wide and about 140 miles long, extending from Wagoner to Grant County, east and west, and from Nowata to Seminole County in a north and south direction. A number of the most prolific oil fields in the world are included in this area as, for instance, the Cushing pool, which broke the oil market in 1915; the Seminole pools, which did the same in 1927; and the Tonkawa pool, which has more sands than any other field and a greater per acre production than any field with the exception of some salt-dome fields of Texas.

The history of oil and gas production in Oklahoma is very interesting. The first well was drilled near Clear Boggy Creek, west of Atoka, in 1885, by Dr. H. W. Fawcett of New York. It was carried to a depth of 1,415 feet and had several good shows of oil and gas, but was finally abandoned on account of the death of Dr. Fawcett, in 1888. Two other tests were drilled within the next few years—one near Tahlequah and the other near Eufaula—but neither was successful. The first successful wells were drilled in 1894, near Chelsea in Craig County, by the Cherokee Oil and Gas Company. Production was found at about 400-foot depth

and the production was 5 to 10 barrels per day. In March, 1897, the Cudahy Oil Company drilled a successful well in the town of Bartlesville, finding the oil at 1,200 feet and giving the name Bartlesville to a producing horizon which was destined to become a magic name in the Mid-continent area later. In 1901, the first well was drilled in the Red Fork area. This well was a good producer and proved to be the necessary inducement to a great campaign of exploration. The Secretary of the Interior began to approve leases in a more liberal manner and by 1905 good wells had been drilled at Red Fork, Bartlesville, Muskogee, Chelsea, Cleveland, and in the Osage Nation. On Nov. 22, 1905, the first well in the famous Glenn pool was drilled in. The second well in this pool produced 700 barrels per day and started one of the most remarkable booms in the history of the oil industry. After the excitement in the Glenn pool had died down somewhat, C. B. Shaffer started a series of tests 5 miles apart, west of the pool. Four were dry holes but the fifth was the well which opened another wonder pool—the Cushing field. This well was drilled in 1912, and produced 120 barrels per day from a depth of 2,250 feet. Within 2 years time the field was producing 225,000 barrels per day—truly a record for those days.

It was at about this time that operators were beginning to appreciate the work of geologists, for the mapping of the Cushing anticline and the evident relation of production to structure was a convincing argument in favor of geological investigations. The magic word "structure" was first used by the oil fraternity in 1914, and from then on the search for such structures became urgent. One company, the Empire Gas and Fuel Company, employed as many as 250 people in the geological department by 1917. It also established a separate department for subsurface work, which was a new departure. Under such an impetus, the surface geology of all eastern Oklahoma was thoroughly mapped by a dozen individual companies, and every anticline found and tested. The detailed mapping was completed by about 1925, and since then very little of such work has been done. In 1920, the wonderful Burbank pool in western Osage County was discovered, in which 117 wells were drilled before the first dry hole was found and 1,700 wells were drilled before the end of 1926.

The finding of the deeper Ordovician production in the Tucker, Wilcox, and Siliceous lime pools as well as the deeper Mississippian

and Hunton lime sands brought with it a thorough study of drill cuttings and of paleogeography, and this has been the keynote of geological work during the last 4 years. Some of the deep anticlines and buried hills were found to be reflected on the surface, but many are not. The outstanding discovery in recent years was the finding of Wilcox production in Seminole and adjacent counties. The first wells were accidental discoveries, but subsequent work has been largely based on geological work and advice. The great importance of this find will be appreciated when it is stated that over 200,000,000 barrels of oil have been taken out of an area of approximately 11,400 acres in a little over 2 years, the per acre production being nearly 18,000 barrels per acre.

Tectonic Elements.—The tectonic elements which have had an influence on the accumulation of oil in northern Oklahoma are the Prairie Plains monocline, the Ozark dome, the Chautauqua arch and its extension to the southwest, and the Hunton arch. The first two of these are surface structures and the others are subsurface structures. In addition to these major structural features, more or less well-defined anticlinal areas have been found, such as the continuation of the granite ridge uplift of Kansas and the continuation of the Beaumont anticline. One of the most important structural elements is the Ouachita geosyncline. Some of the structural elements are shown on the map (Fig. 83), taken from a report on the Permian of western Oklahoma. The Ouachita and the Ozark mountain areas are counterparts of the Appalachian Mountains and the Cincinnati arch in the east. The former are mountains of Paleozoic sediments closely folded and overthrust faulted, both of which features are suggestive of the same age and relationship of the Appalachians and Ouachitas. North of the Ouachita Mountains lies the Arkansas Valley synclinorium in which rocks of Paleozoic age lie moderately folded. This is similar to the great Appalachian geosyncline area between the Allegheny front and the Cincinnati arch. Finally, the Ozark dome is a very broad arch with low dips consisting of rocks older than upper Ordovician, mostly limestones of middle Ordovician age. This again is very similar to conditions in the Cincinnati arch. Because of these genetic relationships, many believe that the Appalachian and the Ouachita Mountains were at one time connected and that trough or graben faulting has severed them in the Mississippi

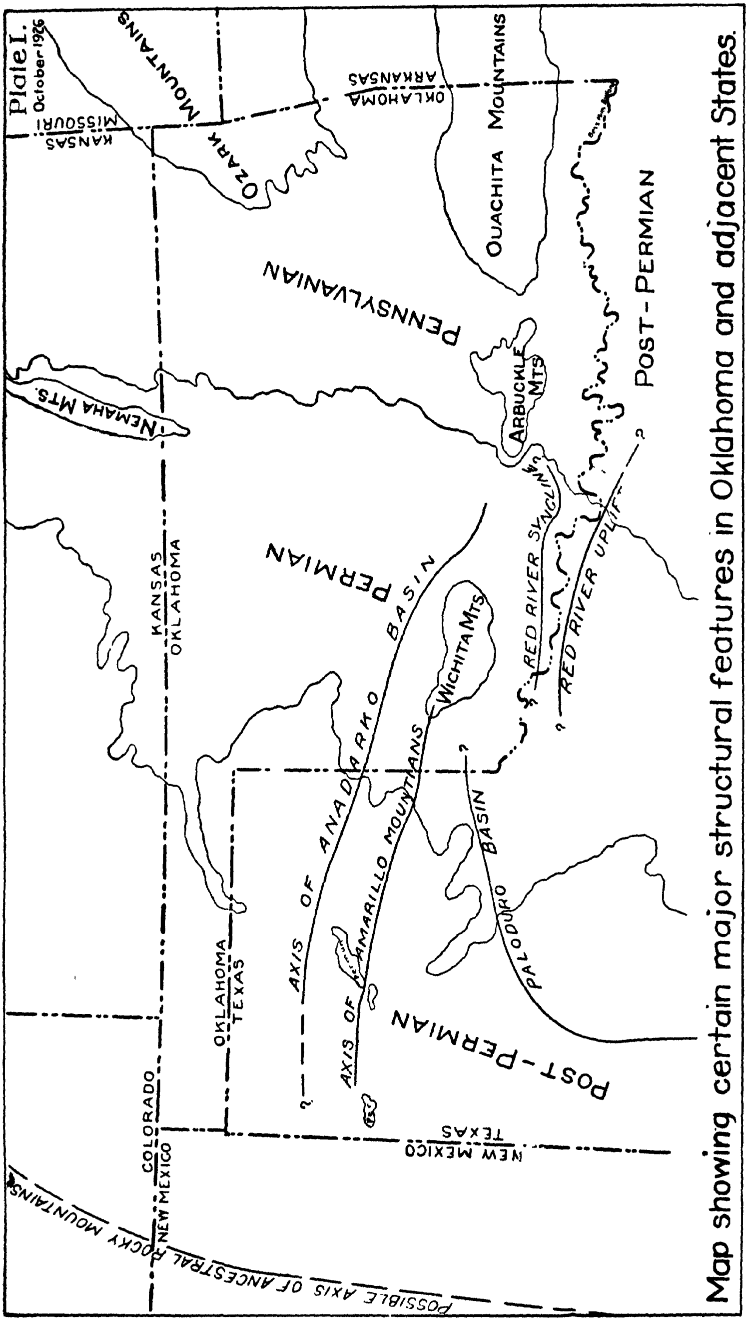

FIG. 83.—Map showing certain major structural features in Oklahoma and adjacent states. (*After Gould and Lewis, Okla Geol. Survey, Circ. 13, p. 11.*)

embayment. The Arkansas Valley trough would thus be the counterpart of the Appalachian geosyncline.

The Arkansas Valley trough can be traced from a point in eastern Arkansas into Oklahoma, the axis trending through Sequoyah, Haskell, and McIntosh counties. It was named after the Arkansas River which flows in it through the state of Arkansas. In Oklahoma the trough is very deep in the eastern part but becomes rapidly shallower toward the west. In northern Pontotoc and western Seminole counties it crosses the Hunton arch and practically loses its identity. On the west side of the Hunton arch another trough along the same trend may be thought of as its natural continuation. This structural syncline has been named the Anadarko basin and a description of it will be found on page 289.

Geological History.—In order to appreciate all the structural elements and their relationship to each other a brief review of the geological history of this part of our continent is necessary. During Cambrian and Ordovician time, much of it was covered by the epeiric sea. Thick beds of limestone and dolomite were laid down with occasional layers of sandstone. In southern Oklahoma, these strata accumulated until over 8,000 feet had been deposited; in southern Missouri, a similar thickness of rocks was accumulated. By the end of Canadian (lower Ordovician) time, the subsidence which had been going on ceased to be general and some areas remained above water. One of these was the central mass of the Ozark dome. During middle Ordovician time, differential subsidence became even more marked and other areas remained above the level of the sea. Such areas are the Chautauqua arch in southeastern Kansas and northeastern Oklahoma and the Hunton arch in south central Oklahoma. The area between these two, running through Osage, Pawnee, Payne, Lincoln, and Pottawatomie counties subsided somewhat during upper Ordovician time but became land after that period. Thus, an ancestral Mississippi embayment is produced, or a southeast dipping monocline with its bordering rim stretching from the Ozark dome west and southwest to the present site of the Arbuckle Mountains. This bordering rim continued across the site of the mountains and connected with a similar arched area now known as the "Bend arch" in Texas (see Figs. 134 and 135, page 333).

In the Ouachita trough, deposition of material continued during Silurian and Devonian times, though perhaps somewhat intermittently, accompanied by further subsidence. During the Mississippian period, the borders of the embayment also subsided beneath the ocean waters, but emerged again before the middle of the period. During all the Mississippian period, however, the main part of the embayment was receiving sediments, and subsidence was more rapid in the axial part of the embayment. During Pennsylvanian time, subsidence in the main portion of the embayment was extremely rapid so that enormous thicknesses of rock were accumulated. On the border of the embayment, subsidence was also taking place but very slowly, so that only very thin portions of the Pennsylvanian succession were laid down there (see Fig. 64, page 176).

About the middle of the Pennsylvanian period, diastrophic movements began in the embayment along a line trending nearly east and west. In Arkansas, the Ouachita Mountains, and in Oklahoma the Arbuckle Mountains were formed. The embayment was thus considerably shortened and narrowed, but deposition still continued. This deposition took place in the Arkansas Valley trough and now extended uninterruptedly across the former border of the embayment far to the west into Oklahoma and the Texas Panhandle and Kansas. In late Pennsylvanian time, the western part of the region was sinking faster than the eastern part, and the shore line gradually shifted westward, so that by the end of the period southeastern and most of eastern Oklahoma was land and subject to erosion. The gentle inclination of the Paleozoic strata toward the west, which is now called the "Prairie Plains monocline," probably dates from this time in the history of the region.

Minor Structural Features.—Superposed upon the major tectonic elements described above are found many minor structural modifications. Prominent among them are certain long, anticlinal trends such as the Blackwell and the Ponca anticlines, the former being a continuation of the granite ridge of Kansas, and the other a continuation of the Beaumont anticline of Kansas. Such long, anticlinal trends, having domes distributed along the axis with saddles between them, are more or less characteristic of the western edge of the productive territory.

Farther east, a different set of structural conditions are characteristic, as, for example, in Fig. 84, which shows a portion

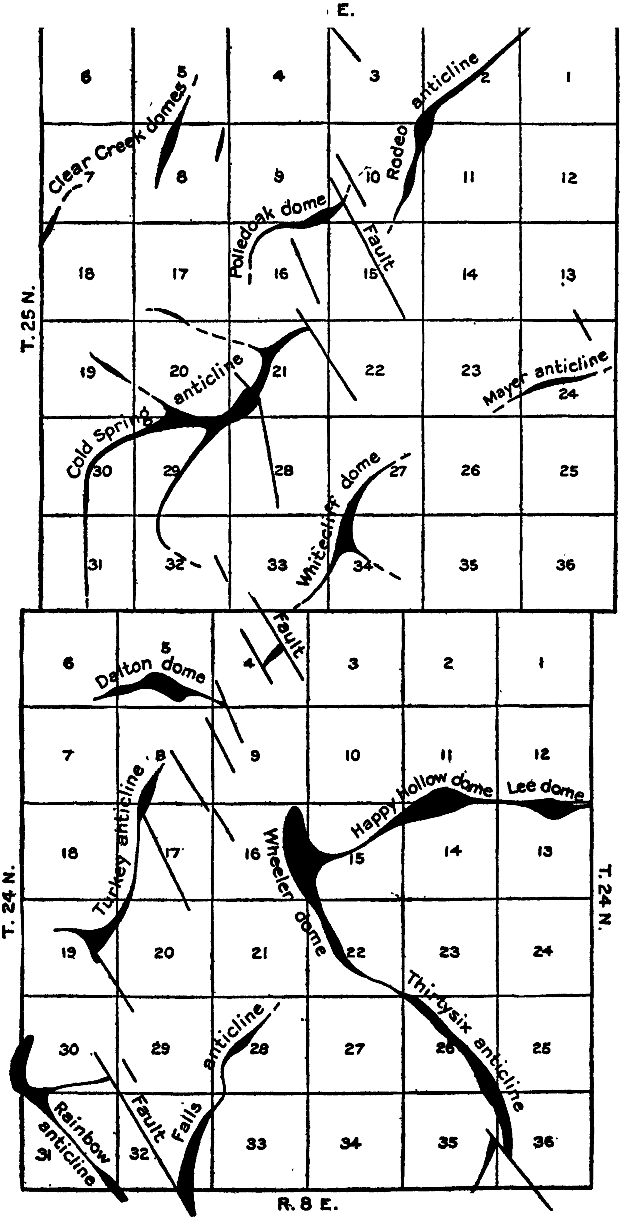

Fig. 84.—Sketch showing approximate positions of the axes of anticlinal folds in T. 24 and 25 N., R. 8 E., Osage County, Oklahoma. (*After Heald and Mather, U. S. Geol. Survey Bull.* 686, p. 156, Fig. 27.)

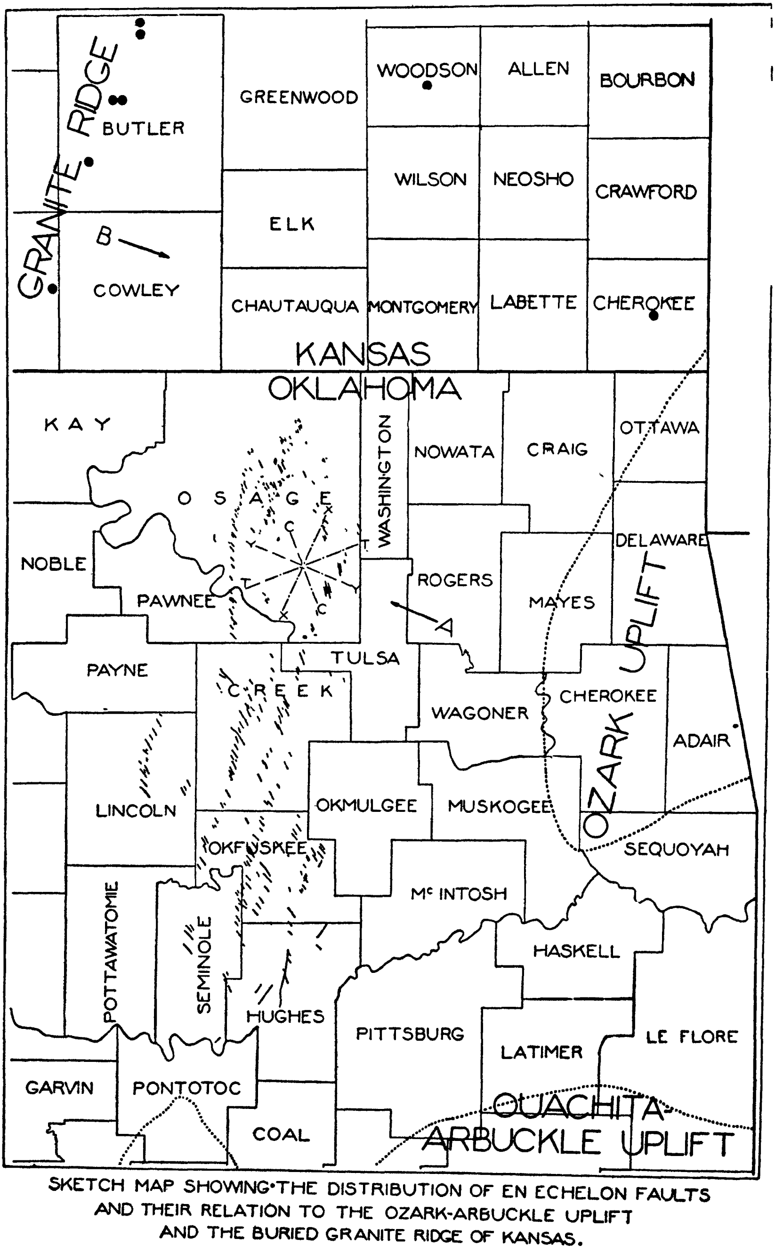

FIG. 85.—Sketch map showing the distribution of en echelon faults in eastern Oklahoma. (*After Foley, Bull.* A.A.P.G., **10**, 294, Fig. 1.)

of the Osage County of northern Oklahoma. It shows many small domes and anticlinal trends, some of which seem to orient themselves parallel to the strike of the rocks, *i.e.*, northeast and southwest, but others of which seem to be quite independent of this control line. Such domes are on the average nearly a mile long and about a half mile wide, and have an average height of 15 to 20 feet. Their greatest elongation is in a direction nearly northeast and southwest, which is almost at right angles to the more precise strike of the faults found in Osage County and in association with the domes.

Farther south in Creek, Okfuskee, and Seminole counties, the faults are even more numerous, but the strike does not change much and they show a very definite tendency to alignment in a direction which closely parallels the direction of greatest elongation of the domes and basins (see Fig. 85).

Many attempts have been made to explain these faults and folds. Gardner, in 1917, suggested that such local folds might be due to vertical transmission of pressure from deep-seated sources in the zone of rock flowage. Three years later Blackwelder suggested that compacting of sediments over buried topography would account for most of the anticlines in eastern Kansas. While agreeing in this with Blackwelder, Powers[1] believes that the spasmodic uplift at different times of the buried hills is partly responsible for the origin of some of the structures.

Geologists familiar with the Appalachian type of structure which is characterized by close folding and thrust faulting, at first attributed folding in Mid-continent areas to tangential thrust. This force can hardly be invoked, however, because of the incompetency of the Paleozoic rocks to transmit a thrust for such distances as would be necessary. Fath[2] was the first to suggest rotational stress transmitted to sediments by shearing in the basement complex. This he believes resulted in the formation of the en echelon faults shown in Fig. 85. As regards the formation of anticlines and domes, he believes that some of them, at least, are due to the change of a fault to a fold toward the surface. Other folds he thinks are due to vertical displacements

[1] Powers, S. B., Healdton oil field in Oklahoma, *Econ. Geol.*, **12**, 594–606, 1917.

[2] Fath, A. E., The origin of faults, anticlines, and buried granite ridge of the northern part of the Mid-continent oil and gas field, *Bull.* U. S. Geol. Survey, *Prof. Paper* 128 *C*, 1920.

of master faults in the basement rocks. The unusual phenomenon of greater folding in the upper than the lower beds found at some places, as, for example, at Cushing, is due to movements at different intervals compensating each other. Foley[1] goes a step farther and explains many of the small folds associated with the en echelon faults as due to compression developed by the rotational stress. He performed experiments in which he covered two wooden blocks with wax and moved one block horizontally relative to the other, developing a master shear plane, above which the wax was deformed. Thus he reproduced

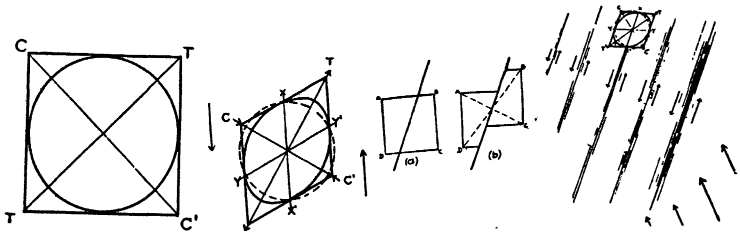

FIG. 86.—Diagram illustrating the strain ellipse and its application to the interpretation of the structural features of northern and east-central Oklahoma. (*After Merritt and McDonald, Okla. Geol. Survey Bull.* 40 C, p. 25.)

effects which are in all essentials similar to the structural conditions observed in eastern Oklahoma. Foley's assumption that the major thrust-producing deformation was from the Ozarks toward the Nemaha granite ridge does not sound convincing. Merritt and McDonald incline to the view that the Ouachita Mountain region or the area immediately south and coutheast of that tectonic element is the seat of activity whence same the deforming thrust. They believe (see Fig. 86) that the resultant of a thrust from this direction would be rotational in character and would be west of north. This thrusting movement acting upon the basement rocks would reopen lines of weakness which already had a direction of 45 degrees with the resultant mentioned. The horizontal differential shearing which would result would diminish westward and northward. Rotational stresses set up in the overlying incompetent beds would result in the dome-type compression anticlines and tension faults. Vertical movement in the basal rocks would give rise to another set of folds and faults which would be alligned parallel to the

[1] FOLEY, L. L., The Origin of the Faults in Creek and Osage counties, Oklahoma, *Bull.* A.A.P.G., **10**, 293–303 (1926).

shear zones. Faults thus produced might resolve themselves into folds; at least they would tend to diminish toward the surface. Asymmetrical folds, which are fairly common and which have the steeper dips on the southeast side, are due to the fact that the thrusting component in the basal rocks is from the southeast. Such asymmetrical folds will have the axis displaced toward the northwest. In some actual cases the Wilcox sand axis is displaced as much as one-quarter of a mile.

A glance at Fig. 85 shows that the faults die out at about the Kansas line. Also, the structural features so prominent in Osage County, shown in Fig. 84, gradually die out in Kansas. This change is probably due to three factors: (1) the decrease in the effectiveness of the thrust in the basal rocks, (2) the thinning of the overlying sediments from south to north, and (3) the change in the character of the rocks from south to north. In the south, sandstones and sandy shales are prominent, whereas in the north limestones and clay shales take their place. Sandstone and sandy shales have a tendency to break rather than bend, whereas clay shales bend rather than break. Limestones, although brittle when subjected to sudden shock, are likely to bend by recrystallization if the thrust is applied gradually.

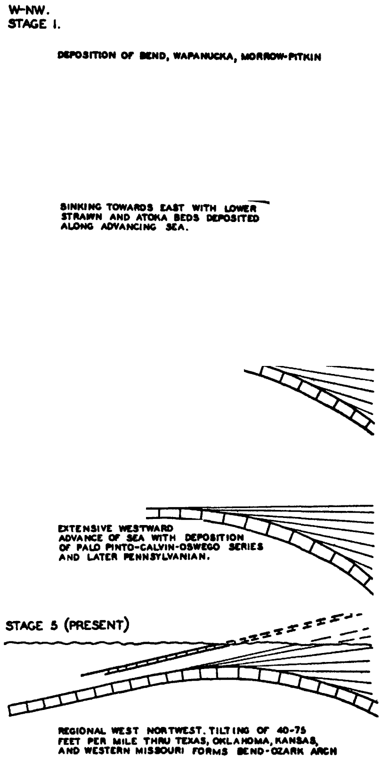

FIG. 87.—Diagram showing progressively the origin of the Bend-Ozark arch based on convergence studies. (*After Levorsen, Bull.* A.A.P.G., **11**, 681, Fig. 15.)

In this connection, it would be unfortunate to overlook Levorsen's suggestion, which may throw a good deal of light on the question of many structures large and small in all parts of the country. In applying the data which he collected in regard to

convergence in Oklahoma, he finds that the apparent progressive sharpening of the dip with depth, as well as the northwest shifting of the subsurface fold which is so typical of the eastern zone of the producing territory, may be explained by convergence alone. This is best brought out by Fig. 87, which shows the great arch made by the union of the Ozark arch in Oklahoma, and the Bend arch in Texas (*a*) at the beginning, (*b*) during subsidence of one side, (*c*) during the encroachment of the sea in Pennsylvanian time, and deposition of the Ft. Scott and related rocks, and, finally, (*d*) after regional warping had impressed the prevailing westerly dip on the surface strata. In substance, it explains how

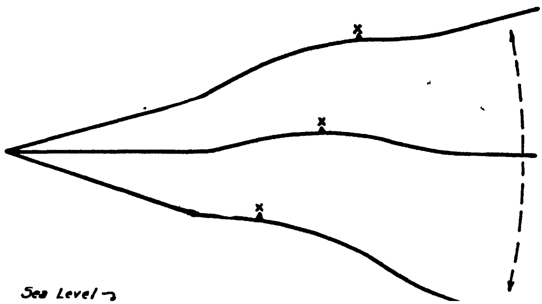

FIG. 88.—Diagram to show how the same dome will contour, sea-level datum, (*a*) as a west-pitching terrace or nose, (*b*) as a dome, (*c*) as an east-pitching terrace or nose depending on the regional dip or tilt of the area. *X* is the highest part of the structure in each case and shows the shifting with depth toward the direction of convergence. (*After Levorsen, Bull.* A.A.P.G., **11**, 671, Fig. 8*B*.)

an arch may be produced by the simple process of tilting a monocline. Figure 88 will also illustrate the principle involved very well. It shows how a plunging anticline (nose) on the surface may become a dome on a subsurface horizon simply because of the fact that unequal subsidence was going on while the strata involved were being laid down so that a tilt in one direction is produced.

Stratigraphy.—The rock succession of northern Oklahoma is very interesting but very difficult. All the Paleozoic systems are represented, from the Cambrian to the Permian, but the older strata are difficult to correlate because they do not crop out and the younger strata are difficult to correlate because they vary so greatly from strata of the same age in adjacent states. A confusing series of names has been applied to the younger rocks,

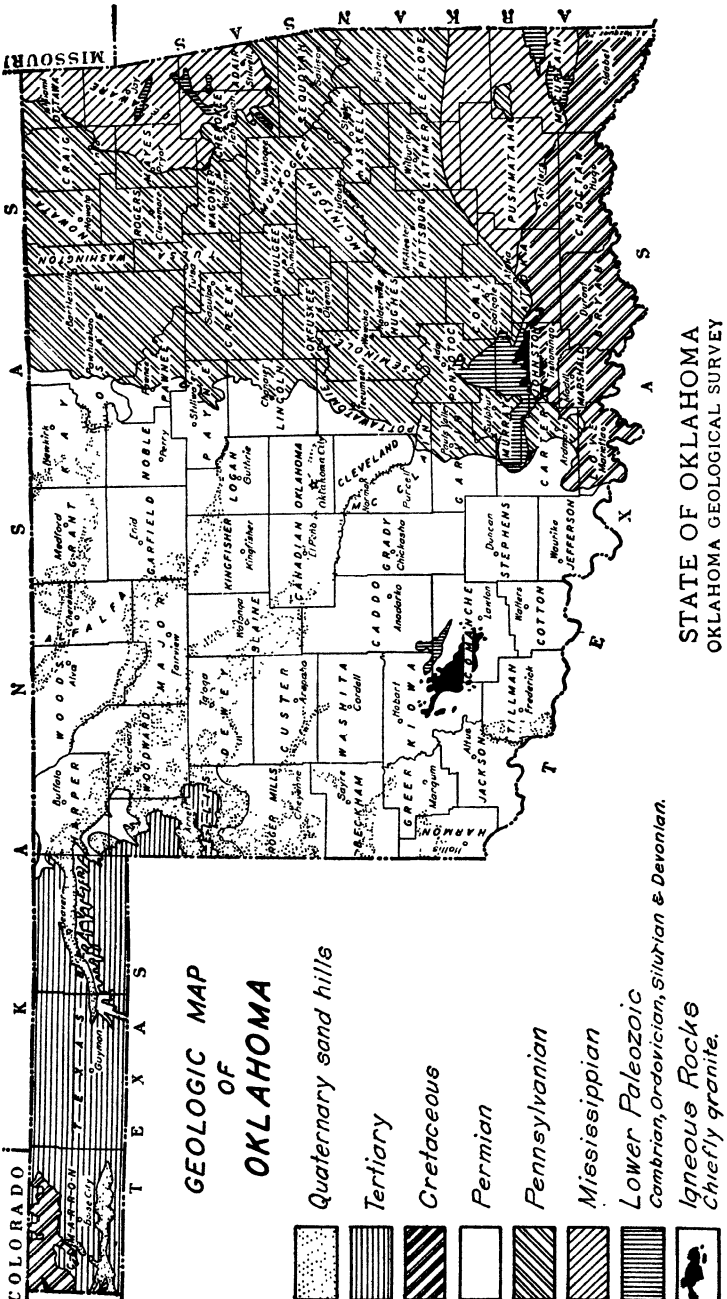

FIG. 89.—Geologic map of Oklahoma. (*After Redfield, Okla. Geol. Survey Bull.* 42, Pl. I.)

and even now there is no great uniformity in the use of many of them. Doubtless, further subsurface work, such as has been done intensively within the last 5 years, will gradually help to clarify the situation. In the following pages the characteristic features of each system are summarized.

Permian System.—The map (Fig. 89) shows that the Permian system crops out in Oklahoma chiefly in the western portion of the state. In a general way, the rocks of this system consist of red shales nearly 3,500 feet thick in which are found at certain levels red sandstones, white gypsum layers, some salt layers, and thin dolomite seams. The red color of these rocks is their outstanding characteristic. On the map (Fig. 89) a line has been drawn called the "color change" line. This line does not coincide with the strike of the Permian rocks exactly, although it does approach parallelism in the southern part of the area. Instead, it cuts across the Permian beds and also involves rocks of Pennsylvanian age. In parts of Osage, Kay, Noble, and Pawnee counties the lower part of the Permian is not red, elsewhere it is. In Kansas these non-red layers belong to the Council Grove, Chase, and Marion formations which contain a number of very persistent limestones. The limestones extend a short distance into Oklahoma and then gradually become thinner and disappear, the two shale zones on both sides merging to form a single mass. Sometimes sandstones appear at about the same horizon as the limestones. All of them eventually become red thus making differentiation into separate formations and members impossible. Therefore, the whole interval in Oklahoma below the line of color change is called the "Stillwater formation." The Wellington formation of Kansas which consists of dark clay shales and thin mud stones with some red and green streaks can be traced across Oklahoma as far as the Arbuckle Mountains, but, like the underlying formation, this also has a red color. The Wellington of Oklahoma is about 600, and the Stillwater about 800, feet thick (Fig. 90, p. 238).

Above the Wellington there is a series of sandstones, sandy shales and clay shales, all red in color to which the name Garber was given.[1] Geologists working in the region of Garber in eastern Garfield County, have distinguished a lower and upper division on account of a difference in lithology. The lower division is mostly shale and has received the name *Lucien shale* member,

[1] AURIN, OFFICER, and GOULD, 1926 (see Bibliography).

the upper division is mostly sandstone and has received the name *Hayward sandstone* member. The Lucien is approximately 250 feet thick and was named from a village in eastern Noble County. The Hayward member is about 350 feet thick and was named from a village in southeastern Garfield County.

At the town of Hennessey, in northern Kingfisher County, the shales above the Garber may be seen. They are different from the other red shales in the section because they are rarely laminated, but more commonly blocky, and break with a conchoidal fracture. Also, the color is a deep maroon red instead of a pinkish red. Finally, they have thin layers of white and green shale from a few inches to 4 feet thick, which may be traced for many miles and which may be used for structure mapping. The lower 250 feet of the formation is called the *Fairmont shale* member and the upper 150 feet of the formation has received the name of *Bison banded* member. The distinctive feature which differentiates these two is the fact that the upper member contains a considerable number of white or green bands of sandy or calcareous shale which are thicker and more numerous than those of the lower member.

The *Duncan sandstone* succeeds the Hennessey shale. It is a white or buff sandstone, appearing in two or three massive ledges, separated by shales, the total being about 250 feet thick. This formation has been traced south around the Anadarko basin and into Texas where it is believed to be the same as the *San Angelo* sandstone. In northern Oklahoma, the Duncan consists of soft friable red sandstone. It is usually cross-bedded, may be conglomeratic, and may contain red shales.

The formation which lies above the Duncan has received the name of "Chickasha formation." It includes all the beds between the Duncan and the Blaine gypsum above. Red clay shales and gypsiferous shales and thin sandstones compose the formation.

The *Blaine gypsum* is one of the most widespread formations of the Permian red beds of America. It has been traced from Barber County, Kansas, entirely across Oklahoma 600 miles into the Panhandle of Texas. At the type locality in Blaine County, it is 75 feet thick and consists of three ledges of gypsum separated by red clay shales.

The *Dog Creek* shales fill the interval between the Blaine gypsum and the *Whitehorse* sandstone. The latter is a sandstone 100 feet thick in southwestern Oklahoma and red in color. Some gypsum lenses occur in it, the most prominent one having been named the Saddlehorse member. Above the Whitehorse lie the dolomites and red shales of the Day Creek formation. This formation is relatively thin but a very important key horizon for surface-structure mapping. It is succeeded by the *Cloud Chief* gypsum which is 100 feet thick and above this lies the *Quartermaster* formation consisting of red shaly sandstone 300 feet thick.

In order to bring out the succession of these red beds, and for purposes of reference, the following table is appended:

Correlation Table of Permian Formations of Kansas and Oklahoma[1]

Kansas		Oklahoma	Thickness, feet	
	Big Basin	Quartermaster	300	
	Hackberry	Cloud Chief	100	
	Day Creek	Day Creek	5	Woodward
	Whitehorse	Whitehorse	100	
	Dog Creek	Dog Creek	200	
Cimarron	Blaine gypsum	Blaine gypsum	75	
	Flowerpot shale Cedar Hills sandstone Salt Plains	Chichasha	175	
	Harper sandstone (upper and middle)	Duncan sandstone	250	
	Harper sandstone (lower)	Hennessey shale Garber sandstone	400 600	Enid
	Wellington Pearl shale of Marion	Wellington	600	
Big Blue	Marion (Exclusive Pearl) Chase Council Grove	Stillwater	800	

[1] *After Gould* (see Bibliography).

Pennsylvanian System.—In Oklahoma, the Pennsylvanian system has been blessed with a superabundance of names. This is due to the fact that the system changes its lithology and

thickness greatly from place to place. The clear-cut division into formations and members which were studied in connection with Kansas is not possible in the adjoining state. This division was largely based on the appearance of persistent limestones in the section. These limestones become thinner in northern Oklahoma and gradually disappear. Sometimes a sandstone comes in at nearly the same horizon, and this may be used for a distance. As a rule, however, the lithologic units in Oklahoma cannot be brought into correspondence with those of Kansas. Within the state, the character of the sediments also varies especially from north to south and it is with difficulty that any group of rocks can be traced. Still, a great many geologists working with subsurface information have contributed to this problem and we are therefore closer to a good correlation table than ever before. Nevertheless, any correlation table made at this date is subject to future corrections. The best table which has appeared in print is the one which is reproduced on p. 236.[1]

In the Ozark region and lying unconformably upon the Pitkin limestone, which is the highest Mississippian formation, is found the Morrow formation consisting of a sandstone at base, limestone in the middle, and a shale at the top, the total thickness being 100 feet. This formation is absent in Kansas and indeed was probably laid down long before any Pennsylvanian deposition began in that state. The Winslow formation in the type locality is 2,300 feet thick and consists of shales and sandstones. Part of these shales and sandstones may be the same as the lower part of the Cherokee. The latter has a definite upper limit which is the Ft. Scott limestone, thus giving one valuable horizon for correlation purposes. According to *Bull.* 35 of the Oklahoma Geological Survey, the base of the Ft. Scott limestone is placed somewhere in the Wetumka shale, which makes the Cherokee formation of northern Oklahoma equivalent to the Savanna, Boggy, Thurman, Stuart, Senora, and Calvin formations of the deeper part of the Arkansas Valley trough north of the Arbuckles. In that district these formations have a thickness of 4,000 feet. The Senora formation has a good deal of coal in the vicinity of Henryetta and this coal suggests a correlation with the coal-bearing portion of the Cherokee in Kansas.

[1] Dott, Robert H., Notes on Pennsylvanian paleogeography, *Okla. Geol. Survey Bull.* 40 J, p. 8, 1927.

CORRELATION OF PENNSYLVANIAN FORMATIONS IN OKLAHOMA

North Arbuckles		Central Oklahoma	Driller's terms	Northern Oklahoma			Kansas (standard)
Pontotoc Ada formation		Pontotoc	·	Eskridge Neva Elmdale Sand Creek Buck Creek		Wabaunsee	Eskridge Neva Elmdale Americus Admire Emporia Willard Burlingame
Vamoosa ·		Vamoosa	Ponca Hoover	Pawhuska Elgin sandstone		Shawnee	Scranton Howard Severy etc. of Shawnee formation
Break(?)		Break(?)	Carmicheal Endicott	Nelagony	Bristow		Douglas formation
Break(?)		Break(?)		Ochelata			Lansing formation
Break Belle City Francis		Break Belle City limestone Francis	Layton	(Avant limestone) Drum Coffeyville (Checkerboard limestone)	Copan	Kansas City	Iola Chanute Drum Cherryvale Winterset Galesburg Bethany Ladore Hertha
Seminole Holdenville Wewoka Wetumka	Glenn	Seminole Holdenville Wewoka Wetumka	Cleveland Squirrel Big Lime Peru Oswego-Wheeler	Lenapah Nowata Oolagah Labette Ft. Scott		Marmaton	LaCynge Lenapah Nowata Altamont Bandera Pawnee Labette Ft. Scott
Calvin sandstone Senora shale Stuart shale Thurman sandstone Boggy shale Savanna sandstone	Glenn	Calvin sandstone Senora Stuart shale Thurman sandstone Boggy shale Savanna sandstone	Skinner Perryman Red Fork Pink lime Bartlesville	Cherokee (Bluejacket)			Cherokee
McAlester shale Hartshorne sandstone		Winslow	Tucker(?) Booch	Winslow			Absent
Atoka Wapanuka limestone Upper Caney		Absent Morrow	Dutcher	Absent Morrow			Absent Absent
Break Lower Caney	Miss.	Pitkin	Lyons	Pitkin Mayes Boone			Absent Boone

The Cherokee formation lies unconformably upon the *Morrow*, and along the state line at the north is 450 feet thick. There it consists of dark-colored shales with sandstones and some coal veins. The most conspicuous sandstone is the *Bluejacket*, which is shown on the state geological map of Miser and crops out in the

northeastern part of the state. Farther west, where it passes under cover, it is called the *Bartlesville sandstone*, which until recently produced the most oil of any sand in the state. In the Arkansas Valley trough or the coal basin of Oklahoma, it is correlated with the Savanna sandstone. As mentioned previously, the Cherokee or its equivalent thickens rapidly to the south, being 960 feet thick at Pryor and, if the correlation with the Coalgate section of Taff[1] is correct as indicated by Dott, then it is over 5,000 feet thick in Pontotoc County. Very likely the Cherokee is the upper part of a series of rocks which overlap toward the north. As indicated in the correlation table, a number of other sands occur in the Cherokee formation all of which are important producing horizons in northeastern Oklahoma. In addition to being the formation which has some of the best reservoir rocks of the state, the Cherokee is also considered the principal source rock of the oil in the state (see Fig. 90).

The formations and members of formations listed in the correlation table for northern Oklahoma are the ones which were used in making the state geological map under the direction of Miser. Some of the names are those in current use but others are new and were taken from manuscripts of Ohern which were never published. The names of formations listed in the table under central Oklahoma are chiefly taken from Taff's reports on the Coalgate and Atoka folios. It includes all the names which are correlated with the Marmaton and the Cherokee formations of Kansas. The other names as high as the Ada formation are names first used by Morgan in his description of the Stonewall quadrangle. All of these formations consist of sandstones and shales, and it is practically impossible to trace any one of them far enough north definitely to tie in with the formations of northern Oklahoma. The one which seems to be most useful for correlation is the *Belle City limestone* which Miser believes is the same as the Dewey limestone, the upper member of the Drum limestone and, therefore, of upper Kansas City age. From a practical standpoint, it is probably not necessary to make correlations any closer than has been done. For, in well-log correlation, certain horizons are characteristic in certain areas and these can be used over a considerable square area. Such a marker in northern Oklahoma is the *Oolagah limestone* or the "Big lime" of the drillers which is produced by the merging of the Altamont

[1] Taff, J. A., *U. S. Geol. Survey Atlas, Coalgate Folio* 74 (1901).

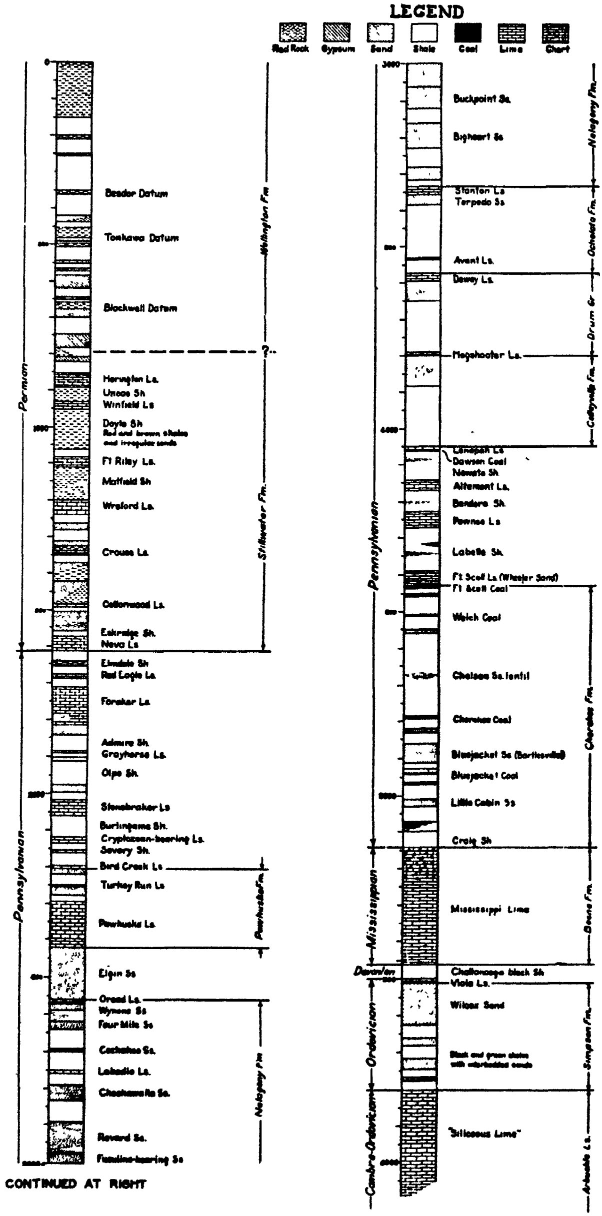

FIG. 90.—Geologic section for north-central Oklahoma. (*Clark and Cooper, Okla. Geol. Survey Bull.* 40 H, Fig. 3.)

and Pawnee limestones of the Kansas section. Another marker is the Checkerboard limestone which lies at about the same horizon as the Hertha limestone of the Kansas section. The next higher marker is the Drum limestone of Kansas which in northern Oklahoma splits into two limestones with a shale break called the *Dewey limestone* (upper drum), the Nellie Bly shale, and the Hogshooter limestone (lower drum). The Hogshooter limestone is the same as the Lost City limestone near Tulsa and the Belle City limestone of the Arkansas Valley trough.

The Ochelata formation above the drum is made up mainly of shales with some sandstones and limestones. The most prominent and usable limestone is the *Avant limestone* which can be traced well into Creek County from the state boundary line. In Creek County, it is usually 10 feet thick or less. The *Elgin sandstone* is another important surface key horizon because it resists erosion better than adjacent formations. It also has been traced quite far south into Oklahoma from the Kansas state line. In Creek County, it is 50 to 60 feet thick and consists of heavy bedded brownish-grey sandstone with some shale partings. Above the Elgin sandstone lies the Pawhuska formation. This formation consists of shales, thin sandstones, and thin limestones.

Mississippian System.—Below the Pennsylvanian rocks of Oklahoma is encountered evidence of the widespread unconformity (which has been discussed in previous pages) in practically every petroliferous province. Figure 91, which is a cross section of the Tonkawa field in Kay County in north central Oklahoma, shows this unconformity well. It will be noted that faulting has occurred after the Mississippian was laid down and erosion has taken place after that, probably removing all or at least a large part of the Mississippian from the crest of the upfaulted arch. The Mississippian rocks are, therefore, not found everywhere present in northern Oklahoma. The names of the Mississippian formations used in northeastern Oklahoma and their time equivalents in other parts of the state are given below, in Fig. 92 which is taken from an article by Buchanan.[1] In this article he describes each one of the formations in considerable detail.

The *Kinderhook* series in the northern part of the state is represented by the Sylamore (not shown on the correlation table)

[1] BUCHANAN, G. S. (see Bibliography), A.A.P.G., **11**, 1309, 1927.

sandstone, the *Chattanooga* shale, and the *Chouteau* limestone. The Sylamore sandstone is a deposit occurring in patches of

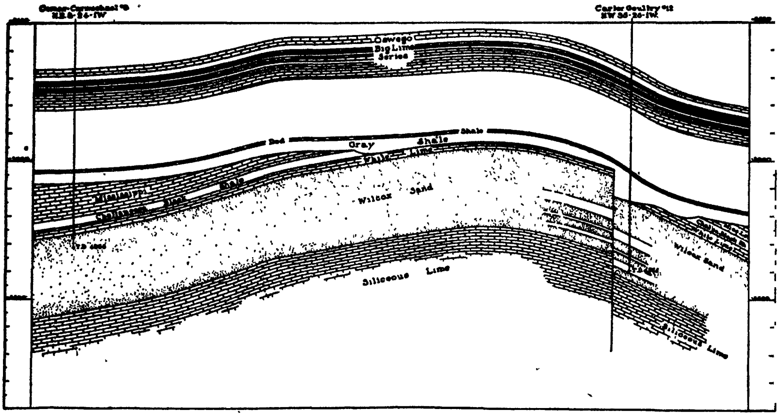

FIG. 91.—Cross-section of Tonkawa field from northeast to southwest. (*After Clark, Bull.* A.A.P.G., **10**, 889.)

relatively small extent and inconsiderable thickness. It is believed by White to represent old-sand dunes covered by early

General Time Scale				N.E. Oklahoma	Arbuckle Uplift & N.	Ouachita Overthrust
		First formation of Pennsylvanian		Morrow	Upper Caney	Jackfork ?
MISSISSIPPIAN. Tennesseean	Chesterian	Bluestone	W.Va.	Carterville		
	Chesterian	Princeton	W.Va.	Carterville		
	Chesterian, Monte Sano	Pitkin	Ark	Pitkin Ls, Carterville		
	Chesterian, Monte Sano	Fayetteville	Ky.	Fayetteville, Carterville	Caney Sh., Lower Caney	Stanley?
	Chesterian, Monte Sano	Tribune	Ky.	Fayetteville, Carterville	Caney Sh., Lower Caney	Stanley?
	Chesterian, Monte Sano	Cypress	Ill.	Batesville, Mayes	Caney Sh., Lower Caney	Stanley?
	Chesterian, Monte Sano	St. Genevieve	Mo.	Batesville, Mayes	Caney Sh., Lower Caney	Stanley?
	Meramecian	St. Louis	Mo.	Moorefield, Mayes	Caney Sh., Lower Caney	Stanley?
	Meramecian	Spergen	Ind.			
	Meramecian	Warsaw	Ill.	Boone Ls. and chert.		
Waverlyan	Osagian	Keokuk	Ia.	Boone Ls. and chert.		
	Osagian	Late Burlington	Ia.	Boone Ls. and chert.		
	Osagian	Early Burlington	Ia.	St Joe member		
	Osagian	Fern Glen	Mo.			
	Kinderhookian	Chouteau	Mo.	Chouteau	Sycamore ls.	
	Kinderhookian	Hannibal	Mo.			
	Kinderhookian	Glen Park	Mo.			
	Kinderhookian	Louisiana	Mo.			
	Kinderhookian	Chattanooga	O.	Chattanooga Sh.	Woodford	Talihini

MISSISSIPPIAN CORRELATION TABLE FOR OKLAHOMA.

FIG. 92—Mississippian correlation table for Oklahoma. (*After Buchanan, Bull.* A.A.P.G., **11**, 1309.)

Mississippian waters. Buchanan states that it is phosphatic in many places and contains sand grains which are pitted and

frosted, suggesting that it might be derived from St. Peter exposures. This sandstone produces oil in places and is then known as the Misener sand. The Chattanooga appears in Oklahoma in its characteristic garb, being a black shale, very bituminous, very widespread and of uniform thickness over great distances. It averages from 40 to 100 feet in thickness. Figure 93 is a paleogeographic map showing the distribution and the

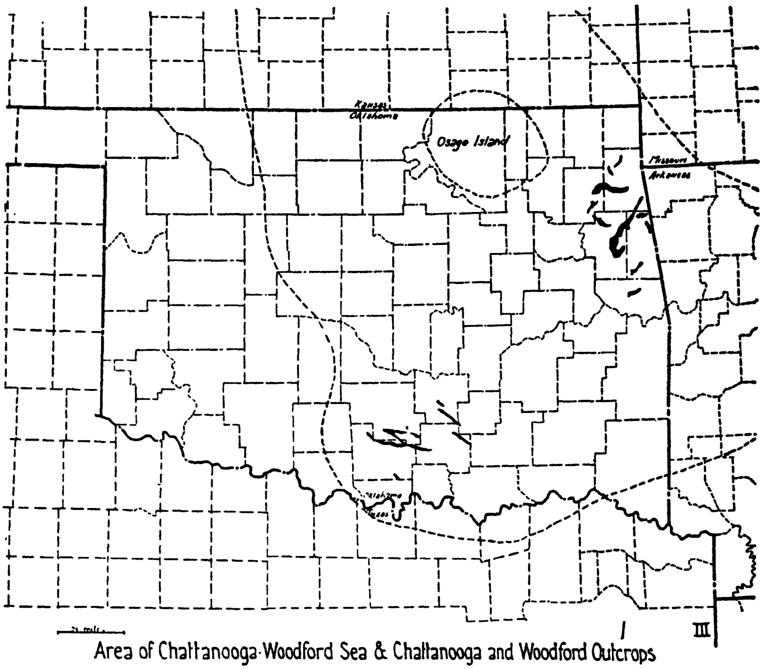

FIG. 93.—Area of Chattanooga-Woodford sea and outcrops. (*After Buchanan, Bull.* A.A.P.G., **11**, 1311.)

outcrops. It will be noted that a small area in Osage County was not covered by Chattanooga waters. The Chouteau limestone seems to be present only in the extreme eastern portion of northern Oklahoma and is not usually recognized in well cuttings of the oil fields. In its place a green glauconitic shale is very often found having a thickness of only a few feet. (*Grassy Creek shale.*[1])

The Osage series of the Mississippian system is represented by the Boone formation which consists of chert and limestone.

[1] See *Okla. Geol. Surv. Bull.* 40 U, p. 15.

As a rule, the chert is more abundant in the upper portion of the mass, and makes up a thickness of 100 to 300 feet. As indicated in the table, the Boone limestone is to be correlated with the Burlington, Keokuk, and a part of the Warsaw formations of the standard section. It is thickest around the Ozark dome and thins rapidly in every direction. In well logs, it is usually one of the best horizon markers and is referred to as the *Missis-*

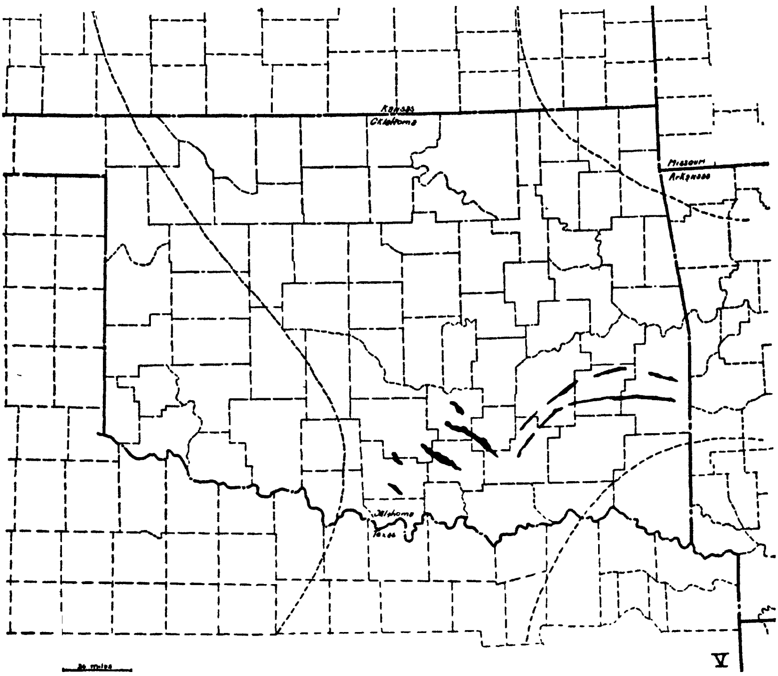

FIG. 94.—Map showing the area of the Caney-Mayes-Moorefield sea and the Caney outcrops. (*After Buchanan, Bull.* A.A.P.G., **11**, 1317, Fig. 5.)

sippi lime by drillers and geologists. This term, however, is also applied to the next higher formation, the *Mayes limestone,* because it may occur at the same stratigraphic level. The Mayes limestone is a black limestone which contains variable amounts of black shale. In thickness it ranges from 3 to 100 feet, being thin in the east and thickening toward the west and south. Figure 94 shows the distribution of the Mayes limestone and its equivalents.

Above the Mayes formation in Oklahoma lies the *Fayetteville shale,* composed of black calcareous strata interbedded with

limestones similar to the limestones in the Mayes formation. It, as well as the overlying Pitkin limestone, was deposited over a limited portion of the state, as shown in Fig. 95. The Pitkin limestone contains some granular earthy and shaly strata as well as pure blue limestone. It becomes more sandy toward the south and is probably (at least in part) equivalent to the *Cromwell sandstone* in south-central Oklahoma which is an important oil-producing horizon.

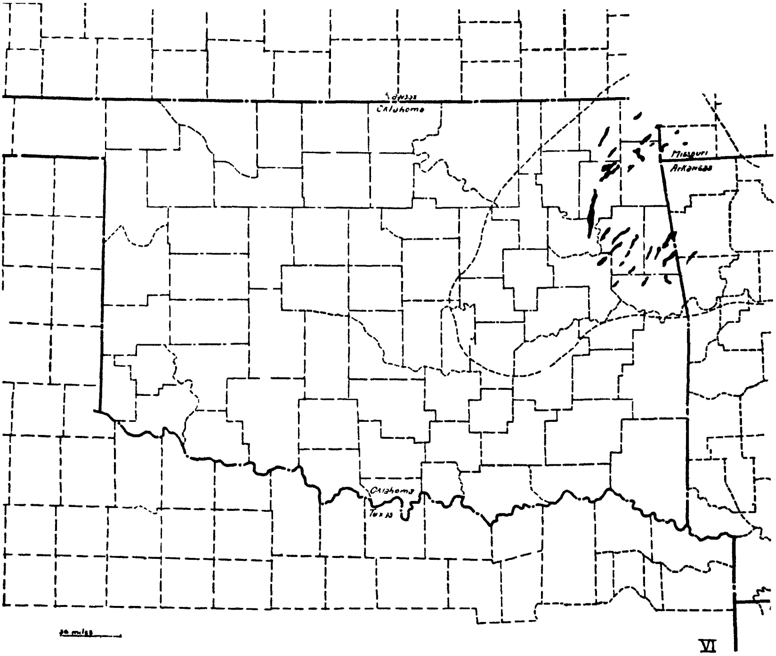

FIG. 95.—Area of Pitkin-Fayetteville sea and Pitkin outcrops. (*After Buchanan, Bull.* A.A.P.G., **11**, 1319.)

Pre-Chattanooga Formations.—Recent subsurface study of the geologists working in Oklahoma has brought out some very interesting facts about the rocks which were laid down previous to Chattanooga time. The most comprehensive statement of these interesting conditions was published by White,[1] in 1926. A map of the areal geology of Oklahoma as it appeared before the black shale was deposited was published at the same

[1] WHITE, L. H., Subsurface distribution and correlation of the pre-Chattanooga series of northeastern Oklahoma, *Okla. Geol. Survey Bull.* 40 B, 1926.

time. It shows that northeastern Oklahoma had the Arbuckle limestone at the surface and that successive bands of younger strata appeared toward the southwest involving all the formations of the Ordovician system and also the Silurian and Devonian systems (Hunton formation) in the region of the Canadian

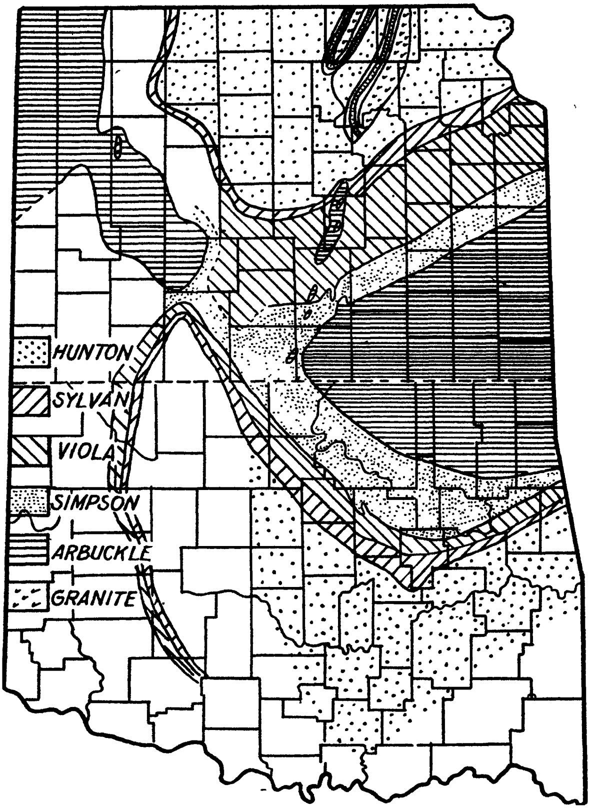

FIG. 96.—Map showing pre-Chattanooga areal geology. (*Based on maps by Morgan, Barwick, Buchanan and White.*)

River. Figure 96 will show these features with some extensions drawn according to more recent maps.

Silurian and Devonian Systems.—The Silurian and Dev nian systems are represented in Oklahoma by the *Hunton formation* originally described by Taff in the Atoka folio. In 1911, Reeds published an article in the *American Journal of Science* in which he presents paleontologic evidence showing that the Hunton

formation consists really of four separate formations of quite different age. These formations he named the Chimneyhill limestone, Henryhouse shale, Haragan shale, and Bois d'Arc limestone (named in ascending order) and placed the line separating Silurian from Devonian between the Henryhouse and Haragan. In subsurface work, it has not been practical to distinguish these formations, although it is sometimes possible, therefore the term "Hunton" is retained and still used by subsurface geologists. In the well cuttings the Hunton formation shows continuous white or grey dolomitic crystalline limestone with only slight variation in lithology from top to bottom. The Hunton formation produces oil in a few places, as in the Stroud area (in eastern Lincoln County) and near the town of Seminole (in central Seminole County). More often it produces large quantities of salt water and for that reason it has been confused with the Wilcox sand. White believes that the St. Clair marble of northern Oklahoma is equivalent to the lower part of the Hunton, because there is no unconformity *below* the Hunton, but a very great unconformity *above* the Hunton. The present distribution of the Hunton formation underground is shown on the map (Fig. 96). In the Arbuckle mountains, the formation has a thickness of about 300 feet. Toward the north it becomes thinner so that in northern Pottawatomie County it is only 50 feet thick and still farther north in Okfuskee County it disappears.

Ordovician System.—The Ordovician system has become the most important system of rocks in Oklahoma during the last few years. Probably more than half of the present production of the state is from rocks of that age. A complete section of Ordovician strata is found only in the Arkansas Valley trough, for toward the north and west from the axis of the trough the strata rise gradually and feather out on the westward projection of the Ozark dome. The close of the Ordovician period must have been marked by great diastrophic movements, for large faults and broad folds appear in the Ordovician rocks wherever the drill has penetrated them. In some areas as the Garber and Oklahoma City fields the strata have been arched up and eroded in such a way that the drill passes from the Cherokee shale of Pennsylvanian age directly into the limestone of Canadian age which forms the base of the system. Instead of being thrown into a simple fold, it is likely that the limestone

was brought up by a thrust fault. Obviously, it is very difficult to detect structural features of this kind at a depth of several thousand feet beneath the surface.

Sylvan Shale.—The highest Ordovician formation recognized in drill cuttings is called the *Sylvan shale.* It has an average thickness of 75 to 125 feet and is remarkable for the uniformity of lithologic character which it exhibits. The topmost 5 to 15 feet consist of greenish blue or light olive-green shales and these are found only when the overlying Hunton is present. Below that are light blue, calcareous shales and toward the base some dark-colored shales. Ulrich correlated the Sylvan shale with the *Maquoketa shale* of Iowa and the *Richmond* of Indiana and Ohio. In northeastern Oklahoma, the Sylvan shale is not found north of a line drawn through Tahlequah, Muskogee, Cushing, and Perry (see Fig. 96).

Viola Limestone.—Below the Sylvan shale in the Arbuckle Mountains a thick mass of limestone (500 to 600 feet thick) appears which has been called the "Viola limestone." In the well cuttings, a twofold division is possible on the basis of lithology. The upper portion is grayish-white in color and coarsely crystalline. The drillers call this portion the "buttermilk" lime. It averages 30 to 50 feet in thickness north of the Canadian River. The lower member is very dense and brownish in color. In texture it resembles lithographic stone and is about 10 feet thick. These two members of the Viola probably do not correspond to the full thickness of the Viola of the Arbuckle region, for there is evidence of a widespread unconformity below them. They correspond to the *Fernvale limestone* of northern Arkansas and Missouri which is of Richmond age. The middle Viola found only in the Arbuckles is of Trenton age and the lower Viola is of Black River age. The Viola is thus seen to overlap toward the north. In wells of northeastern Oklahoma it is not found north of Wagoner, Sapulpa, Drumright (in the Cushing field), and Pawnee.

Bromide Formation.—Below the Viola limestone appear sandy, dolomitic limestones with some green shale and thin sandstones. They have a thickness of approximately 140 feet in northern Oklahoma where encountered in deeper wells. The name was given to this formation by Ulrich in 1911 from a small village by that name on the eastern side of the Arbuckle uplift. There it seems to have a thickness of from 315 to 495

feet. It contains small quantities of oil locally and has no doubt often been confused with the true Wilcox sand which appears lower in the section.

Wilcox Sandstone.—The Wilcox sandstone is the most prolific producing horizon in the state at the present time. In the Arbuckle Mountains, where it may be studied conveniently, it ranges from 100 to 180 feet in thickness. It consists of pure, clean, quartz sand, in which the grains are fine and uniform in size. Another characteristic which differentiates it from other sandstones is the fact that the grains are rounded and frosted. It occupies the same stratigraphic position as the *Burgen sandstone* at Tahlequah, described by Taff and correlated with the well-known *St. Peter sandstone* of more eastern states by Ulrich. This sandstone is very thin at the northern limit of its occurrence, but becomes rapidly thicker toward the south. At Stroud and near Henryetta it is 200 to 300 feet thick, which appears to be a maximum. This sand is not found in wells north of Wagoner and Tulsa nor east of Mervine in Kay County.

Tyner Formation.—Below the Wilcox sand, in the type locality, green sandy shales are found to which the name "Tyner" has been applied. The green shales have dolomitic layers at various horizons and these seem to be particularly abundant near the base. The thickness of the formation in the Arbuckles is about 380 feet. Near the base of the Tyner, or what is called the *Simpson formation* in the Arbuckles, are some sandy dolomites which have been correlated by Edson[1] with the Everton sand of the Missouri section. White states that the Tyner is about 100 to 150 feet thick in northern Oklahoma and that he finds below it a sandstone, averaging 50 feet or more in thickness, which is the same horizon as the *Hominy sand,* and which he calls the Burgen sandstone. As stated above, the Burgen sandstone of Taff's section at Tahlequah is now thought to be the same as the true Wilcox sand.

Arbuckle Limestone.—At the base of the Ordovician system lies a very thick mass of limestone and dolomite. Its thickness, as measured by Decker and Merritt near Ardmore south of the Arbuckle Mountains, is 7,992 feet. Farther north it is encountered in every well which penetrates the overlying strata, and thus it appears to cover a wide area. However, it is much thinner

[1] Edson, Fanny Carter, Ordovician correlations in Oklahoma, *Bull. A.A.P.G.*, **11**, 973, 1927.

to the north. Few wells have gone through it. One well in Creek County found 600 feet of this limestone. Another well in Kay County found the limestone to be 1,010 feet thick. As a rule, granite is encountered below the Arbuckle limestone in northern Oklahoma.

In the oil-bearing area of the state, the term *Siliceous lime* is usually employed for this limestone. This term was first used by Aurin, Clark, and Trager[1] and was intended to apply to the

PRE-MISSISSIPPIAN CORRELATION CHART FOR OKLAHOMA[1]

Arbuckle	Seminole	Northeast	Missouri	Standard
Bois D'Arc	Bois D'Arc		Cooper	Devonian
Haragan			Bailey	
Henryhouse		St. Clair	Sexton Edgewood	Niagaran
Chimneyhill	Chimneyhill		Girardeau	
Sylvan	Sylvan		Maquoketa	Richmond
Upper Viola	Upper Viola	Fernvale	Fernvale	Richmond
Middle Viola	Lithographic limestone	Lithographic limestone	Kimmswick	Trenton
	Limestone shale and sandstone	Limestone shale and sandstone	Decorah	Black River
			Plattin	
Bromide	Limestone and sandstone	Green shale and sandstone	Joachim	Lowville
Upper Simpson	True Wilcox	St. Peter	St. Peter	Blount
Middle Simpson	"Tyner" Simpson	(?)	Everton	Middle Chazy
Hominy sandstone	Hominy sandstone			Lower Chazy
Arbuckle limestone	Siliceous limestone	Cotter	Powell Cotter Jefferson City	Canadian
			Roubidoux Gasconade Eminence Potosi	Ozarkian
			Davis Bonneterre	St. Croixan
Reagan			Lamotte	
Porphyry		Granite	Granite	Pre-Cambrian

[1] Based chiefly on chart by FANNY EDSON and FREDERIC BUSH (published in A.A.P.G. *Bull.* 13, p. 457, 1929).

limestone which was encountered in wells below the Wilcox sand series. In some places oil was found in the upper weathered portion of the limestone. The first place where it was thus found was at *Turkey Mountain*, near Tulsa, and the name of this mountain was transferred to the producing horizon. White states that the Turkey Mountain sand is a highly crystalline dolomite in which the crystals appear quite large (though usually sub-

[1] See Bibliography.

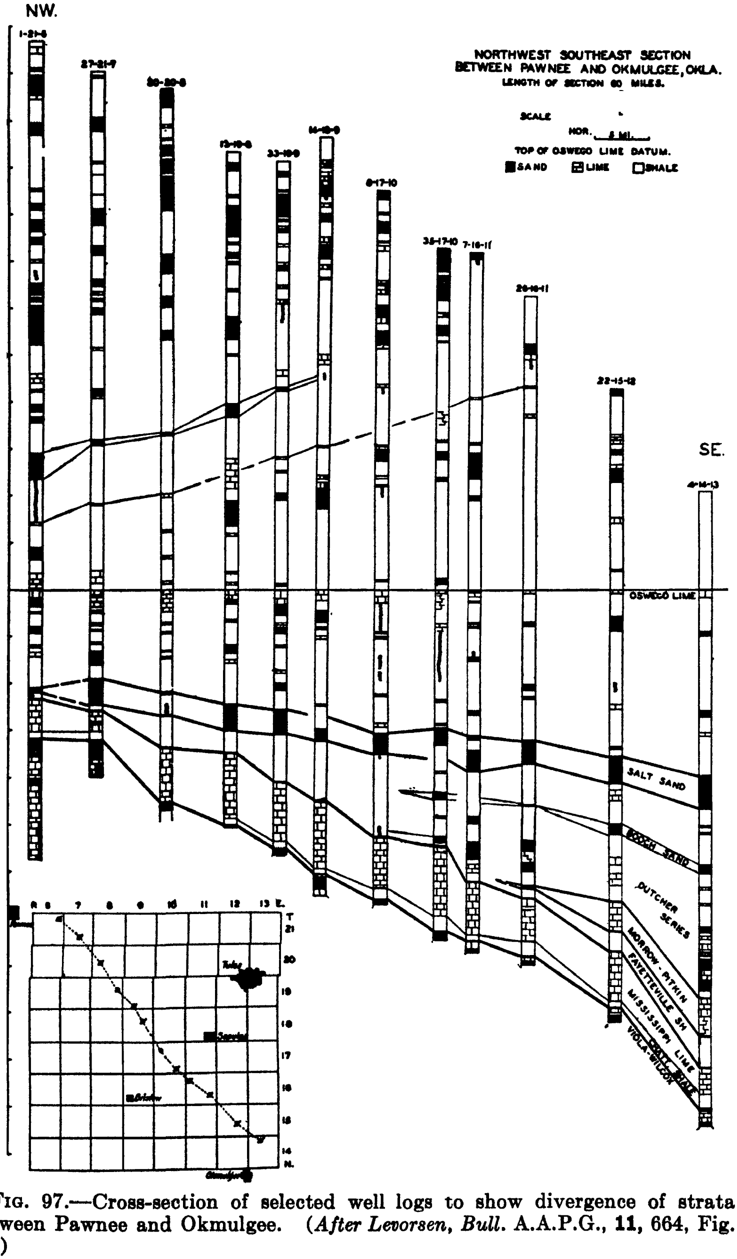

Fig. 97.—Cross-section of selected well logs to show divergence of strata between Pawnee and Okmulgee. (*After Levorsen, Bull.* A.A.P.G., **11**, 664, Fig. 4*B*.)

megascopic) in size. He believes that in places the so-called "Turkey Mountain sand" may be lower Simpson in age. As is usually the case with limestone production the initial flow of wells from this horizon is large, but does not last long. In order

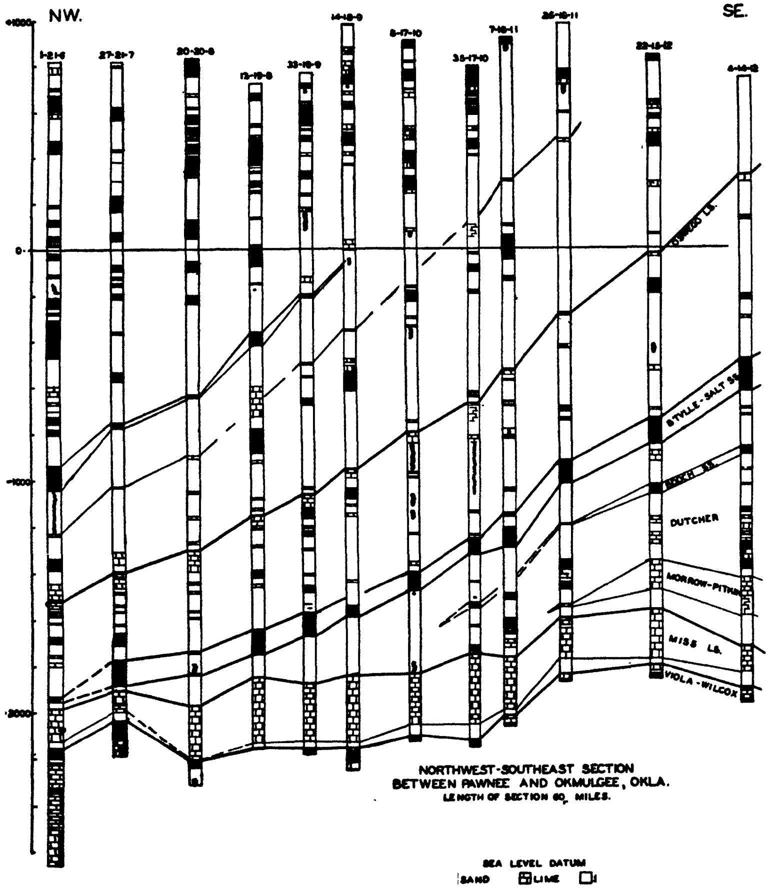

FIG. 98.—Cross-section between Okmulgee and Pawnee with logs arranged on sea-level datum. (*After Levorsen, Bull.* A.A.P.G., **11**, 663, Fig. 4*A*.)

to recapitulate and to indicate the correlation of the Ordovician of northern Oklahoma with adjacent areas the foregoing table is appended (page 248).

Convergence of Strata.—The succession of strata in northern Oklahoma increases in thickness from north to south and also from northwest to southeast. An isopachous map showing

contours of equal amounts of thickness of the strata from the top of the Cherokee to the Wilcox sand horizon is shown in Fig. 64. Most of this great change in thickness is accounted for by the Pennsylvanian rocks. This is brought out by Fig. 97, which shows the gradual divergence of strata between the towns of Pawnee and Okmulgee shown on the insert map. It will be seen that the strata above the Ft. Scott horizon, as well as the

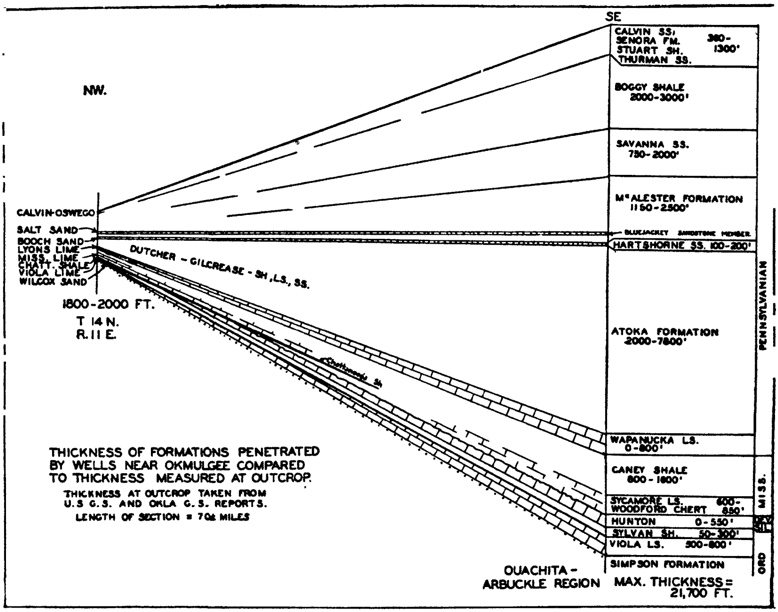

FIG. 99.—Chart showing southeast thickening of formations between wells drilled northwest of Okmulgee and the outcrop of the same formations toward the Ouachita-Arbuckle Mountains. (*After Levorsen, Bull.* A.A.P.G., **11**, 660, Fig. 2.)

strata below that horizon, thicken. The Salt sand, which is the same as the Bartlesville, fingers out to the northwest; the Booch sand below it fingers out much sooner; the Dutcher sand series still sooner; and the Morrow-Pitkin limestone zones soonest. The same area and the same convergence is shown in the Fig. 98 in which sea level is used as a datum plane. In the distance of 60 miles covered by this diagram the thickness of the strata between the Ft. Scott and the Wilcox changes from 2,200 feet in the southeast to 610 feet at the northwest which is an average rate of 26 feet per mile. It does not change uniformly at this rate,

however, for in the Okmulgee district the rate is as high as 70 to 80 feet per mile.

If this convergence is studied still farther southeast from the Okmulgee area, it is found that the interval between the Ft. Scott horizon and the Ordovician rocks changes from 2,000 to over 21,000 feet in the mountain area of southern Oklahoma (see Fig. 99).

Producing Horizons.—The number of producing horizons which have been found productive somewhere in northern Oklahoma is very large. They range in age from lower Permian to the oldest Ordovician limestone—the Arbuckle. It appears that wherever a porous reservoir rock has been placed in juxtaposition with a good source rock, or even where the reservoir rock is separated from the source rock by a small vertical interval, production in the porous rock is possible. In many cases, the porous zone has been elevated with reference to some source rock occurring off to one side so that lateral migration is possible from the latter to the former. This also permits accumulation in a stratigraphic horizon which is lower than the source rock.

Most geologists who have worked in this part of the producing area of our country believe that the Cherokee and the Chattanooga are the important source rocks. They both consist of black shales and are highly bituminous. The shale break in the Ft. Scott limestone is locally very bituminous and there are thin zones of dark-colored rocks at other horizons in the section which may have contributed some of the gas and oil.

Inasmuch as the whole stratigraphic section is thin in the northwestern part of the area under discussion we expect fewer sands there and higher sands. In Kay, Garfield, Noble, and Grant counties, therefore, the highest producing horizons are found. They include the only Permian sands of northern Oklahoma, namely, the Hoy, Kisner, and possibly Hotson sands. The last named is considered to be the equivalent of the Neva limestone which is either the base of the Permian or else placed near the top of the Pennsylvanian. The Hoy sand produces only at Garber in Garfield County where it was first found (on the Hoy farm) in a well drilled by the Sinclair interests, in 1917. This well produced 100 barrels per day at a depth of 1,130 to 1,156 feet. Later a shallower sand correlated with the Winfield limestone was found at a depth of 825 feet. Counting this shallow sand, a total of 18 producing horizons were found to be productive at one

place or another in the field. The shallow sands were found to decline rapidly, but the deeper sands held up well. In order to give the reader a complete record of the important producing horizons in Oklahoma the following table is presented:

TABLE OF IMPORTANT PRODUCING HORIZONS IN NORTHERN OKLAHOMA

System	Formation	Sand	Where found—field or county
Permian	Matfield shale	*Hoy	Garber, Garfield counties
	Crouse limestone	Kisner	Garber, Tonkawa, and Ponca
Pennsylvanian	Neva limestone	Hotson	Garber, Tonkawa, Deer Creek
	Elgin sandstone	*Hoover	Garber, Tonkawa, Billings
	Nelagony	Endicott	Garber, Tonkawa, Ponca
	Bigheart	Stalnaker or	Blackwell and Mervine, Kay county
		*Tonkawa	Tonkawa, Billings, Garber, Ponca
		Musselman	Creek County, Pawnee County
	Coffeyville	*Layton	Garber, Blackwell, Cushing, Creek county
		Jones	Creek
		Cleveland	Osage and Pawnee counties
		Peru	Osage and Washington counties
	Ft. Scott	Oswego	Garber, Osage, and Tulsa counties
		Wheeler	Cushing, Creek County
		Calvin series	Creek, Okmulgee, Okfuskee counties
		Prue-Squirrel	Lincoln, Creek, Pawnee counties
		Skinner	Osage County
	Cherokee	Red Fork	Creek and Tulsa county
		*Burbank	Burbank, western Osage county
	Bluejacket	*Bartlesville	Washington, Osage, Tulsa, Payne, Pawnee counties
		*Glenn	Creek, Okmulgee, and Okfuskee counties
		Taneha (Tucker)	Creek County
	Lower Pennsylvanian	Booch (Tucker)	Okmulgee, Creek, Hughes counties
		Deaner-Gilcrease	Hughes and Okfuskee counties
		Papoose	Hughes
	Pitkin(?)	Cromwell	Hughes and Seminole counties
		Lyons-Quinn	Okmulgee, Hughes, Seminole, and Okfuskee counties
	Fayetteville(?)	*Dutcher	Okmulgee and Creek
		Burgess	Osage, Washington and Rogers counties
Mississippian	Boone	Mississippi lime	Osage County and Billings
	Sylamore	Misener	Okmulgee and Payne counties
		Mounds	Beggs
Siluro Devonian	Hunton	Hunton	Seminole and Pottawatomie counties
Ordovician	Bromide	Wilcox	
	Wilcox	**Wilcox	Okmulgee, Creek, Okfuskee, Seminole Kay, Noble and Garfield counties
	Tyner	Wilcox	
	Simpson	Hominy	Osage County
	Arbuckle	*Turkey Mountain	Tulsa, Creek, Kay, Noble, Garfield, etc.

The Hoover sand produces oil and gas in Kay and adjacent counties only, but it is an important sand in Tonkawa, Billings, Garber, Blackwell and Mervine fields, where it is found at depths ranging from 1,200 to 2,450 feet. The Stalnaker sand produces only at Blackwell and Mervine. It is the same as the Tonkawa sand at Tonkawa, Billings, and Garber. Its average thickness is about 30 feet. The sand in the Coffeyville formation, called

the "Layton sand," is one of the most widespread sands in northern Oklahoma. It is found from the northwestern pools as far east as eastern Osage County and south well into Creek County. Of course, like other sands, it is probably not continuous over that whole area. Important deposits of oil and gas have been found in it. The next important sand that deserves special mention is the Oswego or Wheeler sand which is found in the Ft. Scott member of the Marmaton formation. Besides producing important quantities of gas and oil at widely scattered places it forms the most reliable key horizon for subsurface correlation of well logs. Toward the south it becomes more sandy and it is believed to correspond to the so-called "Calvin series" of the Cromwell pool in Seminole County—a name given to a series of sands found at depths ranging from 1,700 to 2,000 feet. The highest member of the series is the basal sand of the Wewoka formation and the two sands below it are the equivalent of the Calvin sandstone on the outcrop. The position of these sands in that part of the state and their relation to lower sands is well shown in Fig. 100, taken from Levorsen's "Convergence Studies." Below the Calvin series there are quite a number of sands, some of which produce important quantities of oil and others of which are barren. The best of these are the Booch, Gilcrease, Papoose, and Cromwell sands. By some geologists these sands are believed to be equivalent to the *Dutcher sand* and are referred to as the "Dutcher series." By others, the Dutcher sand is placed in the Fayetteville formation which lies lower stratigraphically. Locally the name "Lyons" or "Quinn sand" is used for the Cromwell sand. It will be apparent from the diagram (Fig. 100) that all these sands are probably very lenticular and that more and more sandy zones come into the section as the Pennsylvanian rocks are traced toward the southeast. They are probably older geologically and have no counterpart in the northwest. In other words, the older Pennsylvanian strata overlap in that direction.

At the very base of the Pennsylvanian, and occupying a position similar to the Misener sand, the Burgess sand is found. It probably represents a beach deposit or sand dunes accumulated during late Mississippian or early Pennsylvanian times. It produces in some parts of Osage County and has also been found in the Billings field, but is not productive there. In the middle of the Pennsylvanian system lies a zone of sands which is traceable

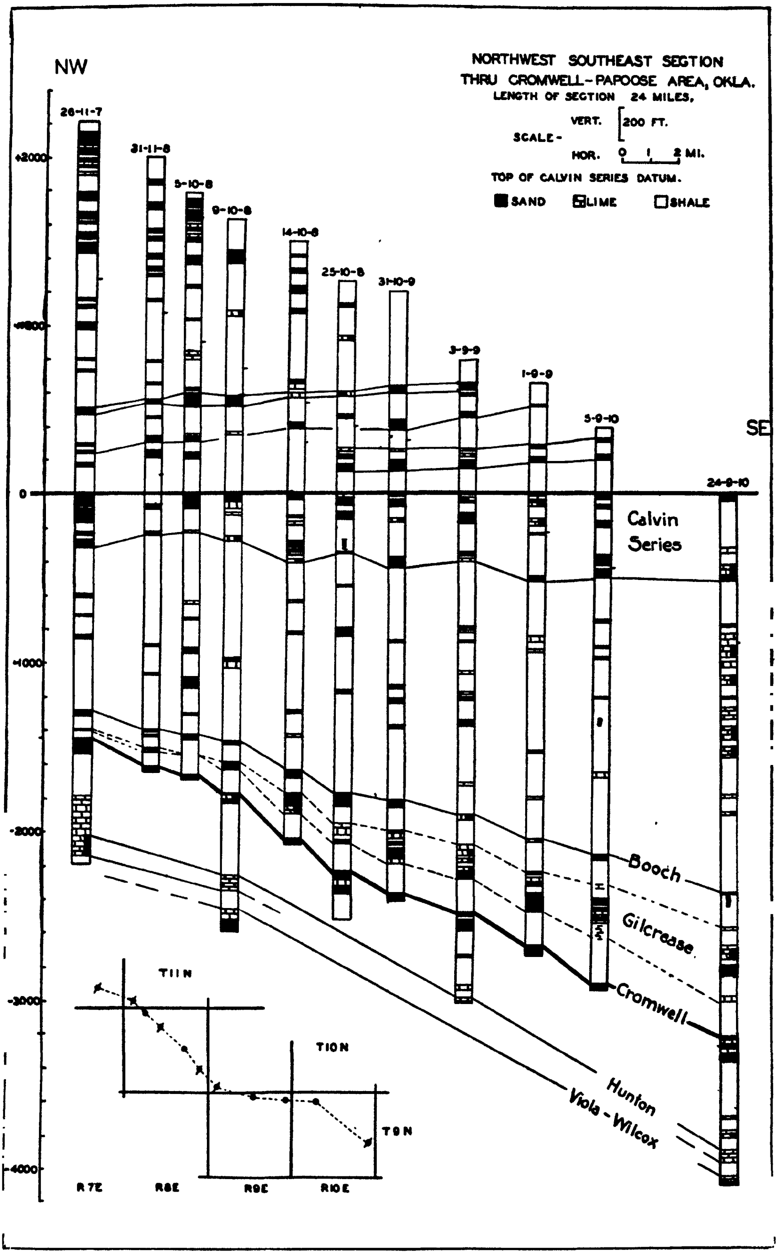

FIG. 100.—Cross-section through Cromwell and Papoose pools arranged with the top of the Calvin series as the datum plane. (*After Levorsen, Bull. A.A.P.G.*, **11**, 662, Fig. 3*B*.)

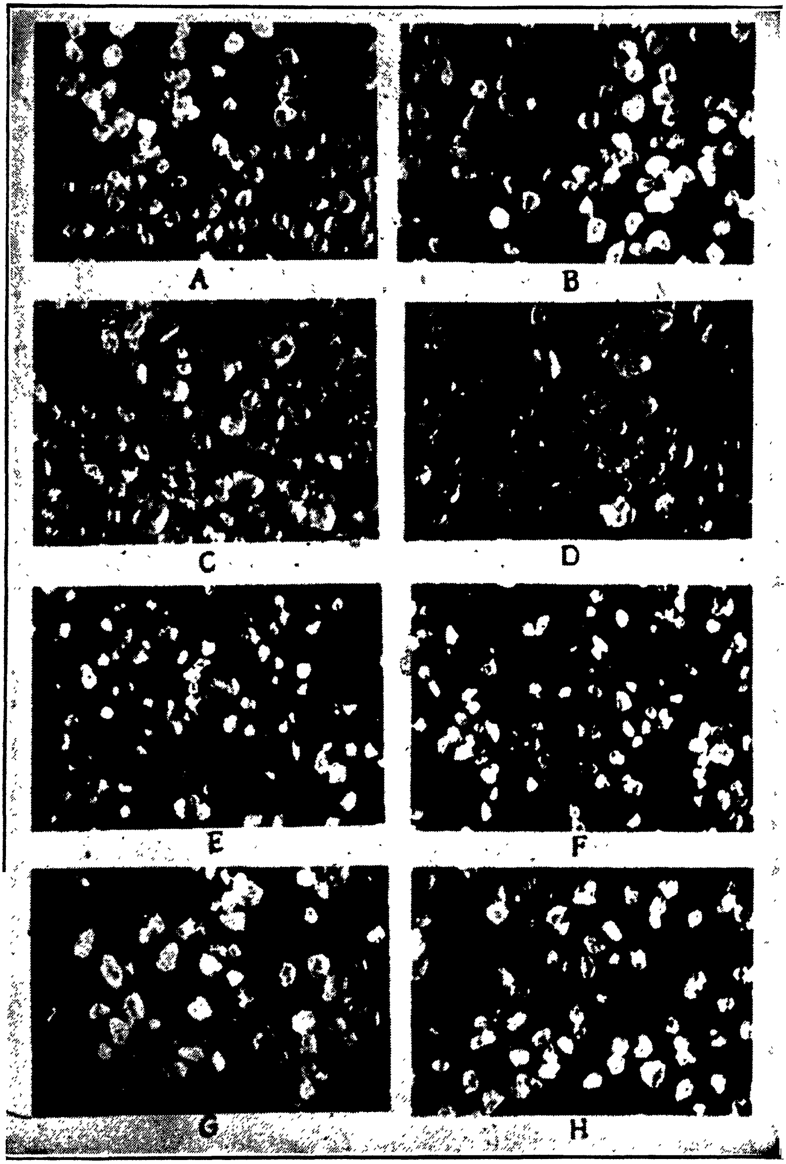

FIG. 101.—*A* and *B*, microphotographs of Wilcox sands; *C* and *D*, microphotographs of Hominy sands; *E* and *F*, microphotographs of Bartlesville sands; *G* and *H*, microphotographs of Elgin sand. (*After Merritt and McDonald, Okla. Geol. Survey Bull.* 40 C, p. 39, Pl. VI.)

over a wider area than any other, although these sands also are large lenses. The most prominent sand of the group is the *Bartlesville sand*, first found in Washington County. At one time it was said to produce 90 per cent of all the oil produced in Oklahoma. Certainly it was a prolific producer in Osage County (eastern), in Tulsa County, as well as in Payne and Pawnee counties. In Fig. 101 are shown some microphotographs of the Bartlesville sand (*E* and *F*). It appears that this particular sample has somewhat poorly sorted grains and that the percentage of well-rounded grains is small. This seems to be a fairly common characteristic of the Bartlesville.

A sand which appears to lie at about the same stratigraphic horizon as the Bartlesville of eastern Osage County is the *Burbank sand* in western Osage County. In the Burbank field it is 30 to 80 feet thick, varies greatly in porosity (from 13 to 33 per cent), and is medium grained. Production in this pool seems to depend entirely on the relative porosity of the sand, being very large where the sand is porous and practically zero where the porosity falls below 13 per cent. Being a sheet sand, it is thinner on the hills and, therefore, the high points of structure on the surface are by no means the most productive.

Another sand correlated with the Bartlesville sand is the *Glenn sand*, named from the Glenn pool in Tulsa and eastern Creek counties. This pool was the first real big pool to be found in Oklahoma. Many wells came in for 5,000 and 6,000 barrels per day and oil became very cheap. Figure 102 shows the Bartlesville or Glenn sand in cross-section; and the reason for the great accumulation of oil in the Glenn pool is apparent. The sand has a thickness of 100 feet where oil is secured. To the east, it thins down rapidly to 25 feet, splits into several parts, and finally pinches out altogether. The Prue sand below the Ft. Scott limestone and the Peru above the limestone are also shown to be lenticular. West and south of the main pool, the Bartlesville sand is present for many miles but there it carries salt water. The boundary between oil and water in 1927 stood at about the contour line of 950 feet below sea level. In this pool there is also a sand below the Glenn which is called the "Mounds sand." This is correlated with the Wilcox by Wilson.[1] It produces a heavy gravity oil in this pool which is contrary to the usual

[1] Wilson, W. B., *Bull.* A.A.P.G., **11**, 1056.

thing, furthermore, the production has not been very large, which is also somewhat unusual.

Pre-Pennsylvanian Sands.—Ten years ago, very little oil was being produced from sands older than the Pennsylvanian. Some had been found, it is true, but they were not recognized as such, and the stratigraphy below the Bartlesville horizon was not understood. During recent years enormous strides have been made by geologists in subsurface work and the stratigraphic-relationships are now pretty well clarified. The surprising amount

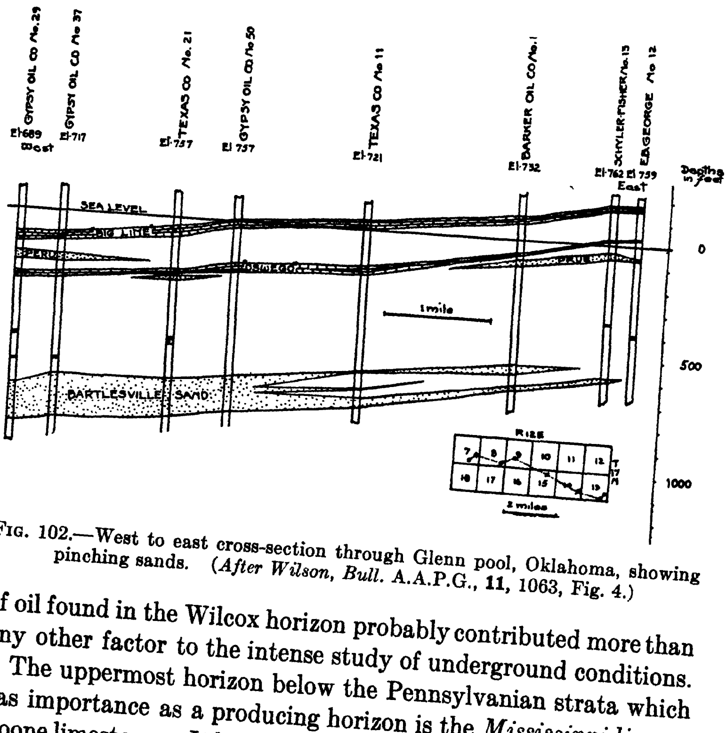

FIG. 102.—West to east cross-section through Glenn pool, Oklahoma, showing pinching sands. (*After Wilson, Bull.* A.A.P.G., **11**, 1063, Fig. 4.)

of oil found in the Wilcox horizon probably contributed more than any other factor to the intense study of underground conditions.

The uppermost horizon below the Pennsylvanian strata which has importance as a producing horizon is the *Mississippi lime* or Boone limestone. It has been found to be porous locally and thus becomes a reservoir for oil. In Osage County, a number of small pools draw their oil from this zone, and it has been found to yield small quantities elsewhere, but on the whole the production is not large, though it may be phenomenal for a short time. At the base of the Mississippian lies the *Misener sand* which is thought to be a local dune deposit. It has not produced much oil up to date. In the vicinity of Beggs, in Creek County, it was

called the "Mounds sand" and that is one of the places where it produced a good quantity of oil.

The Siluro-Devonian horizon called the "Hunton lime" was first found to contain oil in Pontotoc County of south-central Oklahoma. It was discovered in 1921, and the first well produced 125 barrels per day. Two other wells were brought in shortly after this in Seminole and Pottawatomie counties (Maud) which produced from the same horizon. Since then, oil in commercial quantities has been found 5 miles northwest of Stroud in Lincoln County and also near the town of Seminole. Elsewhere, only small showings have been found, which probably indicates that weathering on the upper, unconformable surface did not proceed long enough to cause the proper porosity to develop.

In the Ordovician system, the Sylvan, Wilcox, Tyner, and Arbuckle formations are producing horizons. The Sylvan consists mostly of shale, but the thin sands within the shale have produced oil in small quantities at a number of places. The *Wilcox* is the outstanding oil-producing formation of Oklahoma today. Its great thickness, splendid porosity, and fairly wide distribution make it the premier oil sand of the Mid-continent region. One of its distinctive characteristics is the well-rounded character of the individual grains (see Fig. 101). It was first found in Okmulgee County, at Beggs, and a short time later in Creek County (1918). The sand was named from the Wilcox Oil Company, which drilled in the first gusher from this horizon. In 1919 and 1920, many pools were brought in with production in this sand, as for example, the pools in central Creek County and eastern Lincoln County. Later it was found farther south and, finally, in 1926 production was discovered quite by accident at Wewoka and Seminole (near the southernmost portion of the producing territory in the area under discussion). The remarkable production of the Seminole area is a matter of common knowledge, over half a million barrels per day having been produced for a time in 1927.

The Wilcox pay zones at Seminole are from 20 to 80 feet thick. Farther north the thickness increases somewhat. The total thickness of the sand in Creek County is over 200 feet in many places. Near Stroud and Henryetta, it reaches its maximum of about 300 feet. Oil is found at several levels within the sand body, as many as three pay zones being found in some places.

These pay zones are separated by sand lenses of small porosity, or sometimes by thin shale breaks, or dolomite breaks.

At the base of the Simpson formation (which includes the Bromide, Wilcox, and Tyner) there is often a sand or sandy dolomite which has been called the *Hominy sand.* It was so

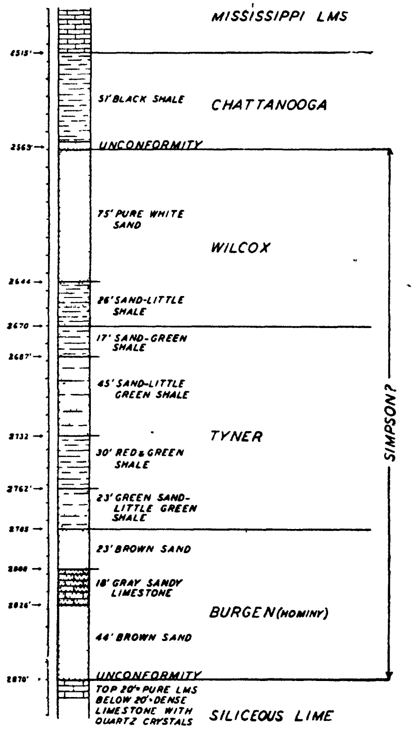

FIG. 103.—Typical well log in Creek County showing the strata below the Mississippi lime. (*After Merritt and McDonald, Okla. Geol. Survey Bull.* 40 C, p. 42.)

called because it was thought to be the source of the deep production around the Hominy pool in the western part of Osage County. Since that time, it has been shown that this production really comes from the Siliceous lime. Nevertheless, there are a few pools which do produce oil from a sandstone near the base of the Simpson, although in most places it seems to be too tightly cemented to offer good reservoir possibilities.

The lowest producing horizon in northern Oklahoma is of Canadian (lower Ordovician) age and is called the *Turkey Mountain sand,* or Siliceous lime. It is the weathered surface of the

Arbuckle limestone. In some places, weathering of this limestone has proceeded for ages, as for example on the Chautauqua arch, where erosion lasted from upper Ordovician time through Silurian, Devonian, and into Mississippian time. It must be assumed that in such places the Siliceous lime horizon is pretty low in the Arbuckle formation and may even be of Ozarkian age. If that is the case, the oldest known oil horizon of importance is in northeastern Oklahoma. In many places where this horizon was found to contain oil, its age was not suspected. That was the case at Cushing, where the Tucker sand is the Siliceous lime. Subsurface study in recent years has shown that this horizon produces in Garfield, Kay, Osage, Pawnee, northern Creek, and Tulsa counties. Figure 103 shows the position and thickness of the Ordovician producing horizons in Creek County. Figure 90, p. 238, shows the same formations with the addition of the Viola lime in north central Oklahoma, Kay County, etc.

Relation of Production to Structure.—Geologists in greater numbers have been at work in this area than in any other area of similar size and they have discovered and described more details of structure and production than we have on record from any other area. It is not possible to separate the producing territory into zones characterized by certain dominant types of structure as was the case in Kansas, because here the stratigraphic position of the sand must be considered in conjunction with its own characteristic structure. Roughly, however, a division into an eastern and a western zone is possible. The eastern zone includes all pools lying in Washington, eastern Osage, and eastern and central Creek counties. The western zone includes Garfield, Kay, Noble, Pawnee, Payne, and western Creek counties. In the eastern zone, in general, the surface structures are low and small and in the western zone they tend to be high and large. In the eastern zone east of Osage County, it is difficult to find a structure with a closure and the same is true to a large extent in Tulsa, Okmulgee, Okfuskee, and Hughes counties. In the eastern part of the Osage, small domes and short anticlines are common (see Fig. 84) with many faults of small throw and short length. This type of structures persists toward the south.

In a general way, it may be said that the structure below the surface becomes more pronounced than the structure on the surface. Figure 104 of the Phillipsville pool in Okmulgee County

illustrates this as well as any other. *A* is the surface structure and shows a faulted monocline with a slight suggestion of a nose or two; *B* is the structure on the salt sand and shows a closure of 20 feet on a terrace; *C* shows the structure of a deeper sand

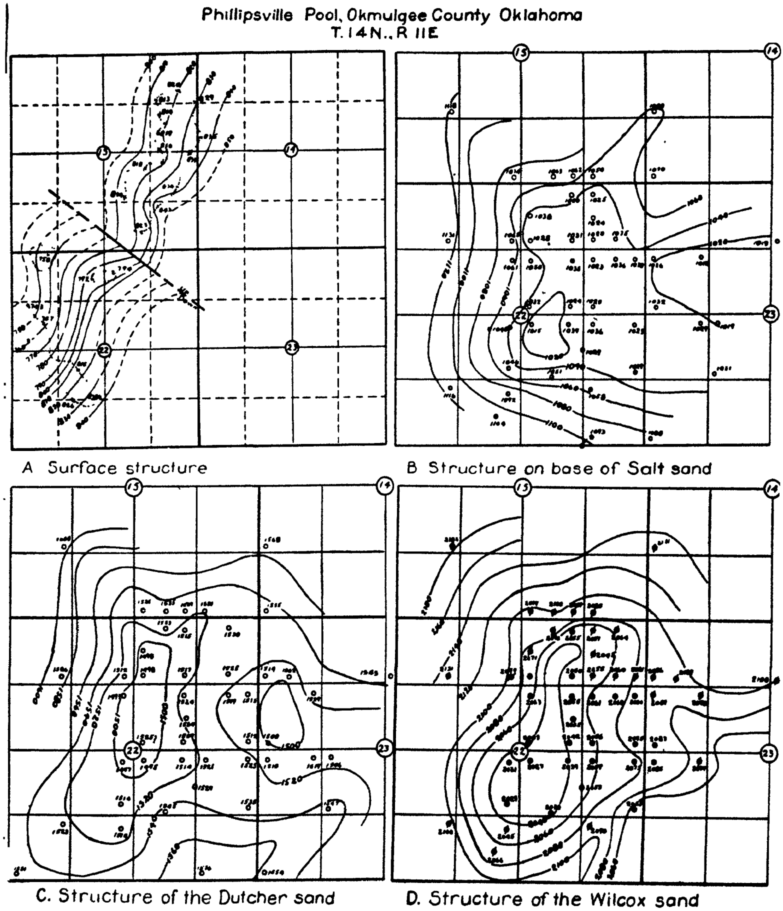

FIG. 104.—Structures in the Phillipsville pool of Okmulgee County. (*After R. W. Clark, Okla. Geol. Survey Bull.* 40 F, p. 19, Fig. 4.)

which has a closure of 20 feet also but the terrace has two domes instead of one and is wider; finally, *D* shows the structure on the Wilcox sand where a closure of about 40 feet is found. It will also be noticed that the focal point of the structure has not shifted much.

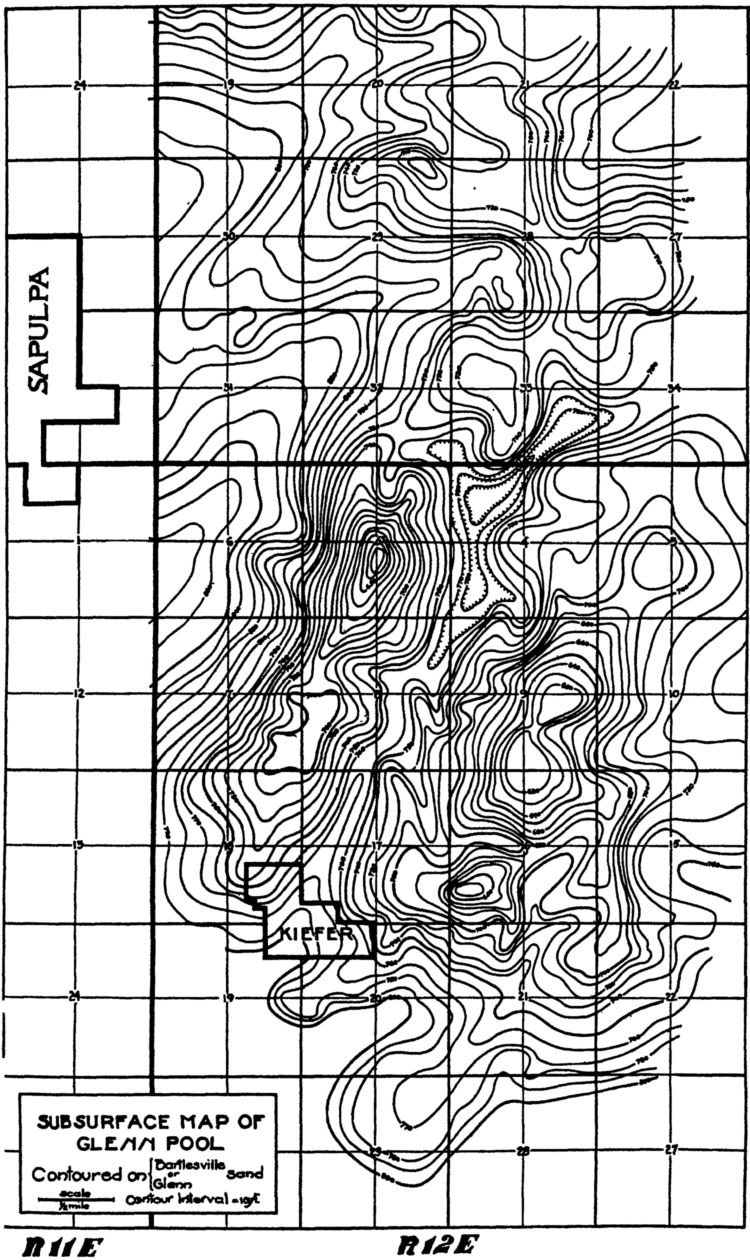

FIG. 105.—Subsurface map of Glenn pool, Oklahoma, contoured on Bartlesville sand *below sea level.* (*After Wilson, Bull.* A.A.P.G., **11**, 1059, Fig. 2.)

To a large extent, production in the eastern zone is independent of the surface structure. One of the best illustrations of this fact is the Glenn pool, referred to previously. It is located in the northwest part of T. 17 N., R. 12 E., of Creek County, and the surface structure is monoclinal. The subsurface structure on the Bartlesville sand in shown in Fig. 105. This map shows a very irregular upper surface of the Bartlesville sand, which is

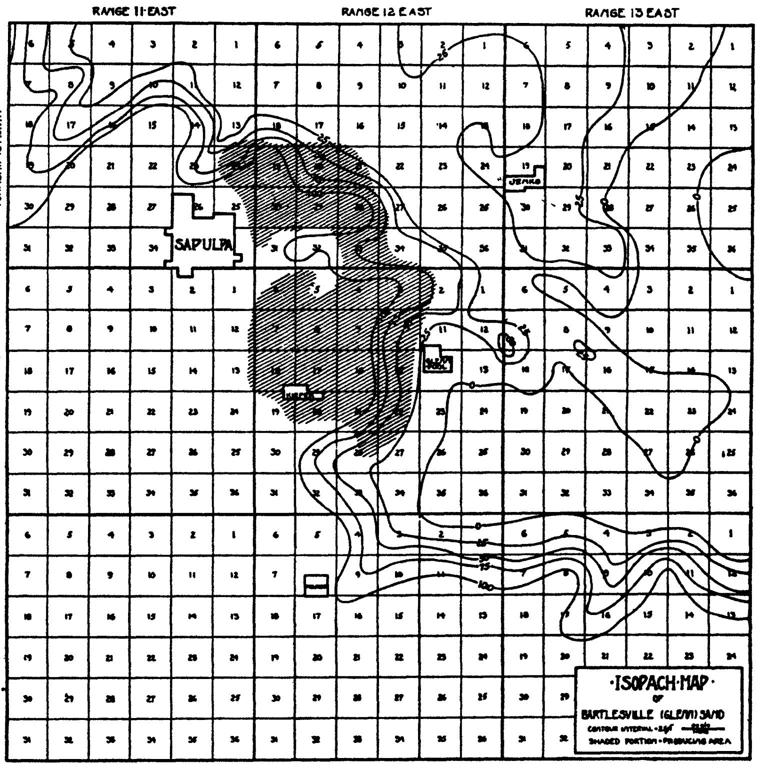

FIG. 106.—Isopach map of Bartlesville sand, Glenn pool, Oklahoma. (*After Wilson, Bull.* A.A.P.G., **11**, 1064, Fig. 5.)

probably due to irregular deposition and not to structural deformation. The real structure would be better shown by a map contoured on the base of the sand. Such a map would probably show a dome in Sec. 5 and another in Secs. 9 and 16, for in those parts of the pool the underlying Ordovician also shows domes or hills. A careful study of the character and extent of the Bartlesville sand, made by Wilson, indicated that accumulation had taken

place here because the sand pinches out up the dip and water fills the sand down the dip (see Fig. 106). In this case, therefore, the porosity of the sand and partly its thickness are alone responsible for the oil accumulation. The map (Fig. 106) shows by means of contours the lines of equal thickness of the sand. It shows that practically no production was obtained where the sand is less than 25 feet thick. By contrast to this condition, the map (Fig. 107) is presented. It shows the structure on the Wilcox sand horizon and also the production from that sand. In this case there is a remarkably close relationship to structure. Only the domes or areas showing closures have oil in them. This condition seems to be quite the rule in the eastern zone of the producing territory in northern Oklahoma, and when it was learned by geologists that noses on the surface frequently had domes in the Wilcox horizon under them, and that such domes are usually productive, the whole region was carefully combed for them. This resulted in many small pools being found, none of them larger than about 80 acres in extent, except Tonkawa, Depew, Seminole, and Wewoka.

Burbank Field.—In order to show more clearly the relationship of production to structure a few typical fields will be described in detail. The Burbank field is one of the most interesting and in many respects one of the most instructive. It is located in the western part of Osage County not many miles from the northern state boundary and was opened up by the Marland Oil Company in May, 1920. The oil rights in Osage County are auctioned off by the federal government at certain intervals of time, the successful bidder agreeing to pay a certain sum for the right to drill for oil and extract it. If oil is found, the usual royalty of one-eight is also paid to the Osage Indian tribe. At the time the first well was drilled in, only a few tracts in this part of the Osage Nation had been sold at auction, because oil producers had found that the Bartlesville sand of eastern Osage pinches out about the center of the county and little interest had been displayed in the western side. Since the first well was brought in, thirteen sales have been held by the government, and the later ones were marked by some large sums paid to drill a quarter section. The highest price paid to date is $1,990,000 for the NE. 1/4 of S. 14, T. 27 N., R. 5 E. The field now covers 170 quarter sections or over 40 square miles, over 2,000 wells have been drilled and more than 140,000,000 barrels of oil have been taken out of the area. Some

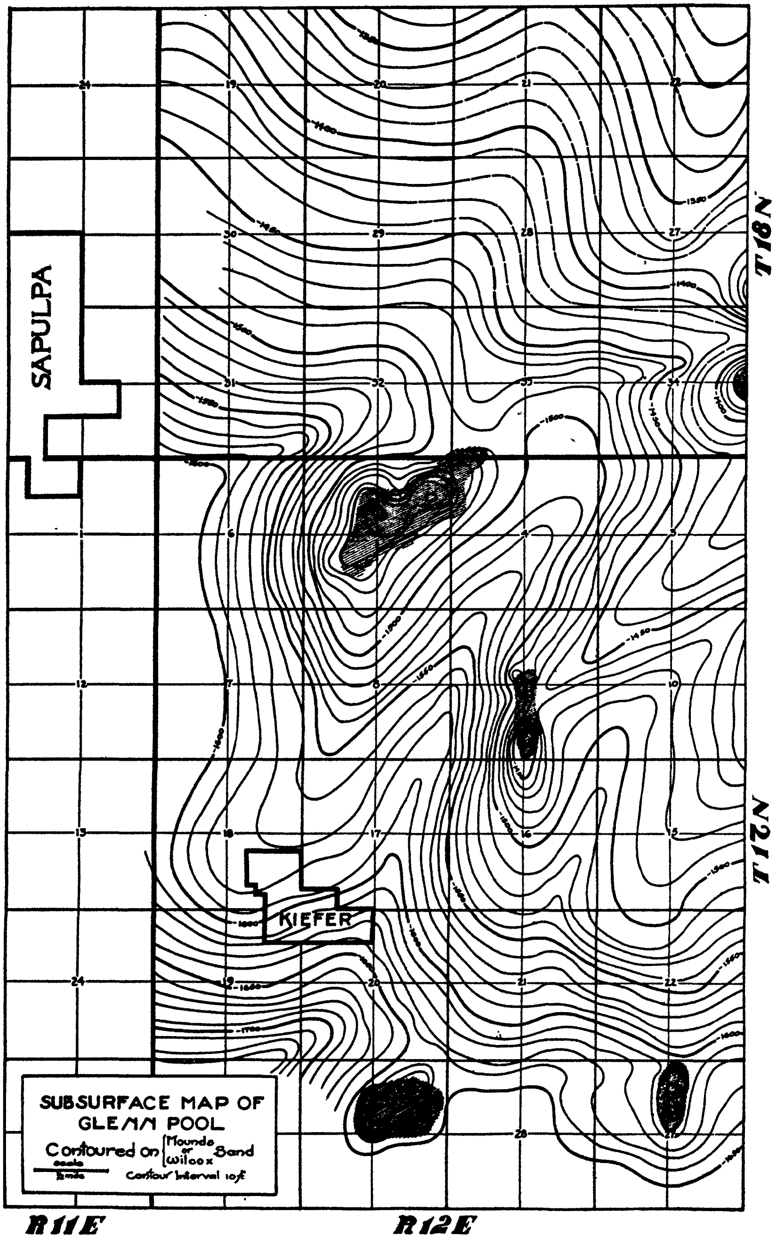

FIG. 107.—Subsurface map of Glenn pool, Oklahoma, contours on Wilcox sand *below sea level.* Shaded portion are areas of Wilcox production. (*After Wilson, Bull.* A.A.P.G., **11**, 1061, Fig. 3.)

quarter sections have produced 20,000 barrels per acre, and the average is 6,500 barrels per acre.

The stratigraphy of this part of the Oklahoma fields is graphically shown in Fig. 108, taken from Sands' excellent article. It shows that the Permian system lies at the surface but is very thin. A complete section of Pennsylvanian rocks is present nearly 3,000 feet thick. Beneath the Chattanooga shale, there is an unconformity, and the Wilcox sand of the Ordovician directly underlies the shale. The Arbuckle limestone (Siliceous lime) is 800 feet thick and below it is granite.

The surface structure of the Burbank field is shown in Fig. 109. It will be noticed that there are two small domes, of one or two 10-foot closures. On these domes the first two wells were drilled. They were not particularly good wells, and later much better production was found some distance away from the domes and lower on the dip. Outside these domes, the monoclinal dip of 40 feet to the mile westward seems to be the prevailing structure, yet production is scattered all over the 40 square miles from northwest to southeast. Quite evidently, the production has very little to do with the surface structure. In the subsurface structure the relationship at the depth of the producing horizon is more pronounced. Figure 110 shows that the two little domes in Sec. 9 and in Secs. 1 and 36 are

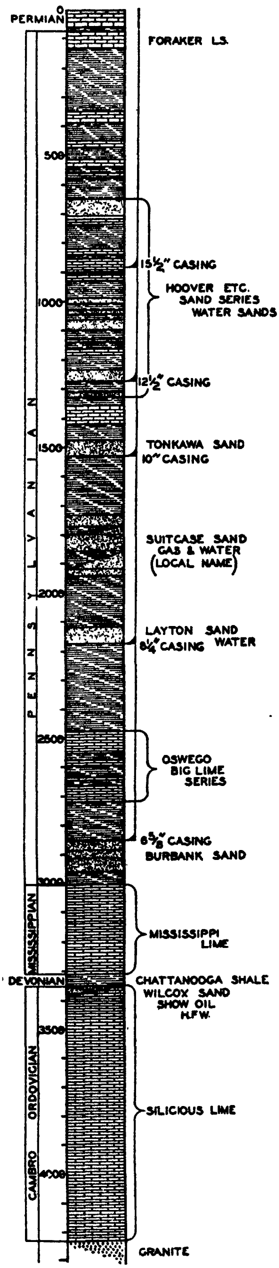

FIG. 108.

FIG. 108.—Type log, Burbank field, Osage, and Kay counties, Oklahoma. (*After Sands, Bull. A.A.P.G.*, **11**, 1053, Fig. 5.)

somewhat more accentuated, the closure being 30 feet now. Also, there are many small domes of 10-foot closure and many small basins. These are very largely due to irregularities of deposition

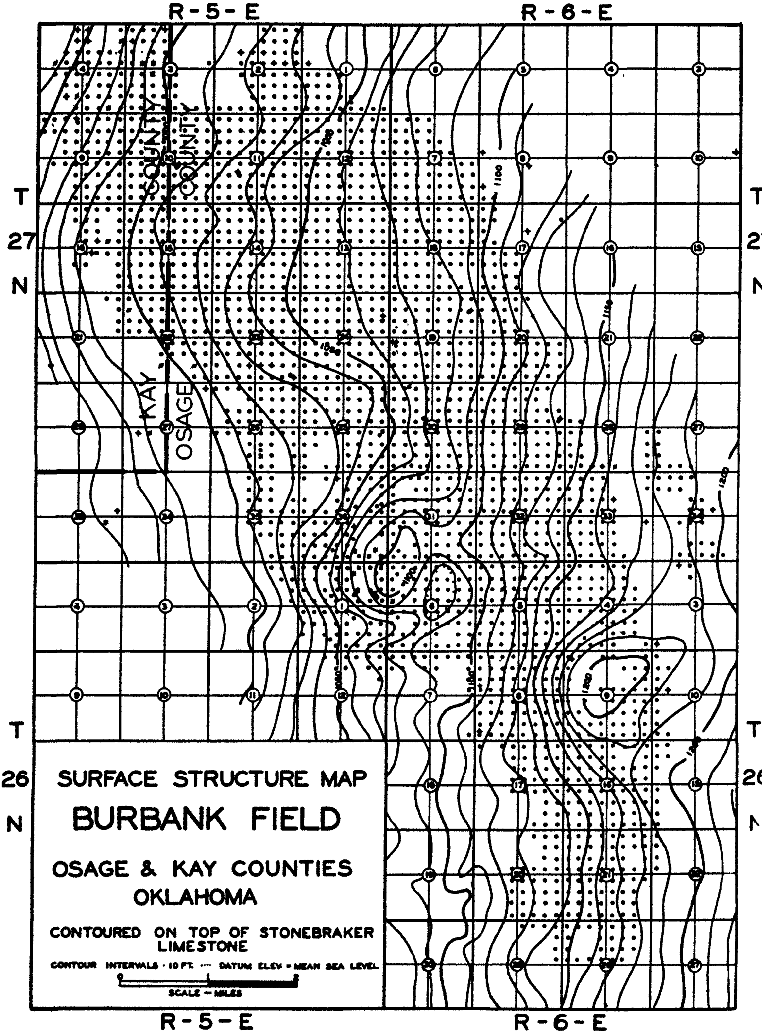

FIG. 109.—Surface structure map of the Burbank field. (*After Sands, Bull.* A.A.P.G., **11**, 1047.)

rather than to structural deformation, therefore it must be concluded that structural conditions have had very little influence on the accumulation of oil.

The reason for the great quantity of oil in this pool evidently lies in the character of the sand. Sands states that the sand is a

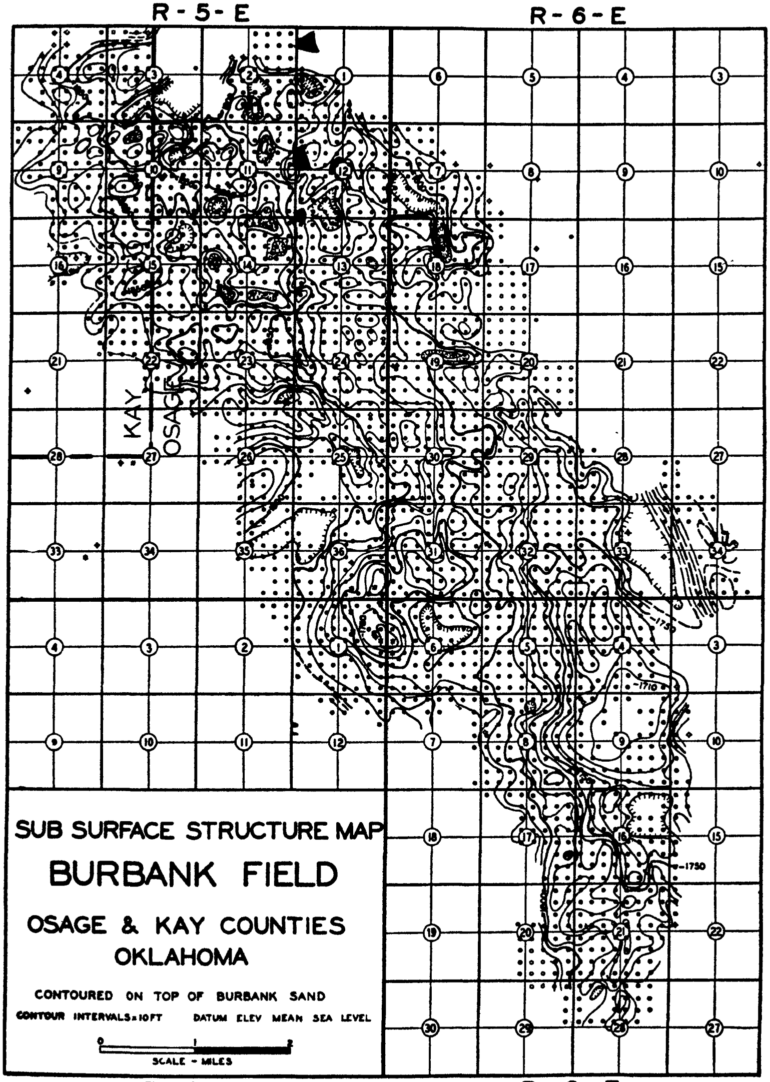

FIG. 110.—Subsurface structure map of the Burbank field contoured on top of the Burbank sand. (*After Sands, Bull.* A.A.P.G., **11**, 1049, Fig. 2.)

fine-grained siliceous sand, having a calcareous cementing material and ranging from 50 to 80 feet in thickness. It shows a pore

space of from 13 to 33 per cent by volume, according to Melcher's determination. A thin shale break is present in the sand about 50 feet from the base so that where the sand is thickest 30 feet

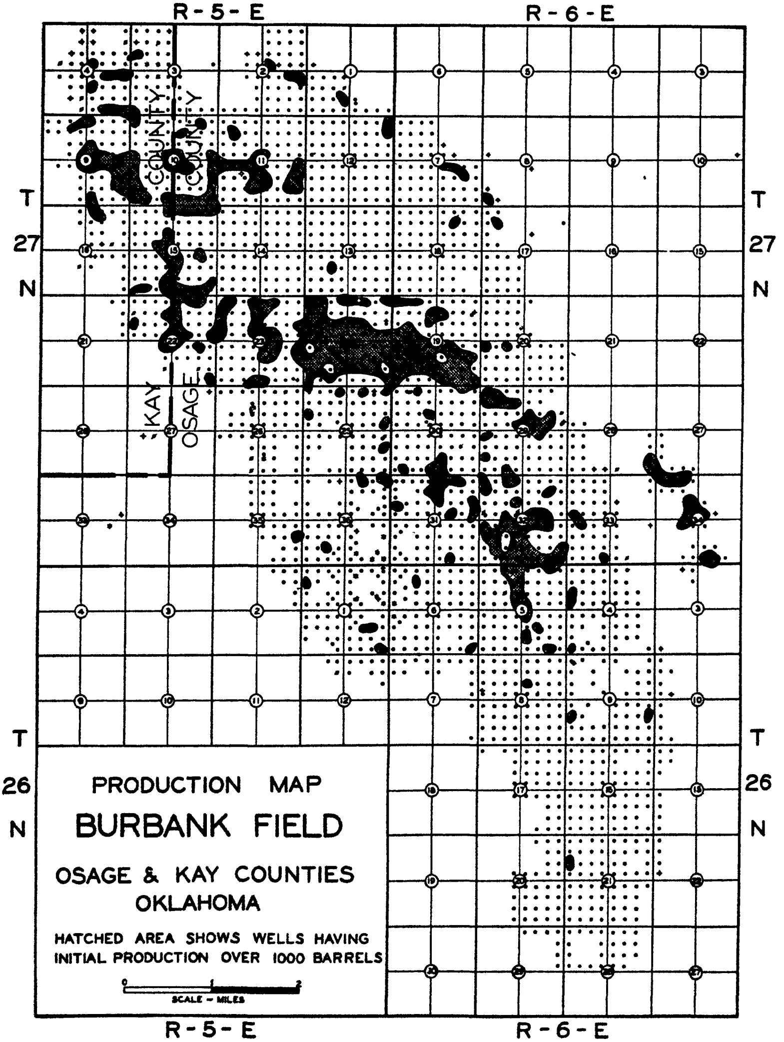

FIG. 111.—Production map of the Burbank field. (*After Sands, Bull.* A.A.P.G., **11**, 1050, Fig. 3.)

of sand lie above the break and then only gas is found in the upper part. Oil is found in both parts of the sand and there are sometimes three or four different pay zones showing that differential

porosity divides the sand into productive and unproductive zones. It might be concluded, therefore, that production would be controlled entirely by porosity of the sand. This conclusion was reached by Melcher,[1] who states that the greatest rate of production will be found in areas of largest average percentage of pore space, regardless of relation to structure, and that the largest output per day will also be found to depend on the average percentage of pore space. Sands states that the most prolific portions of the field are in the northwest part, several miles from the highest point structurally and from 100 to 150 feet below it on the dip. Figure 111 shows the producing area and the patches in which the large wells were found. It will be seen that the most porous areas of sand are scattered about promiscuously and that many of them are very small. A curious feature brought out by this map is the narrow zone of highly productive patches trending northwest and southeast on the eastern edge of the field. This zone is scarcely a quarter of a mile wide and grades into the impervious shale which limits the field in the direction toward the northeast. This rather abrupt termination of the sand body in that direction explains why oil should have accumulated in the Burbank field, but it does not explain the peculiar, high-porosity patches along the edge. It is not at all unlikely that the fringing zone is an ancient barrier. Barriers are thrown up by waves at some distance from shore and parallel to it. If that interpretation is correct, the main area of the field represents a beach or near shore-sand, blanket deposit and the shore line is to be sought somewhere to the southwest.

Tonkawa Field.—The Tonkawa field is located in Kay County, and its position with reference to major structural elements is shown in Fig. 83. It is one of the phenomenal fields of Oklahoma if not of the world. No less than 15 producing horizons are found in the field, often as many as 7 producing on one location. Besides that it has produced an average of over 40,000 barrels per acre, which is also a very exceptional condition. Over half of the per acre production comes from one sand, the Wilcox, which had produced 22,000 barrels per acre by the end of 1927. The stratigraphic section for this field is similar to the generalized section for north-central Oklahoma shown in Fig. 90, p. 238.

[1] Melcher, Texture of oil sands with relation to the production of oil, *Bull.* A.A.P.G., **8**, 716–774, 1924.

Permian rocks with a thickness of 950 feet crop out on the surface. The Pennsylvanian is present in nearly full thickness, but the Mississippian is absent on the top of the structure (see Fig. 91) and appears only on the flanks of the dome. The upper Ordovician is also absent, so that the Cherokee shale rests directly on the Viola limestone.

Tectonically the Tonkawa field lies between the Granite ridge-Blackwell anticline trend, characterized by high-faulted domes, and the Beaumont-Ponca anticline trend, characterized by high domes with a very steep east dip. The Tonkawa field

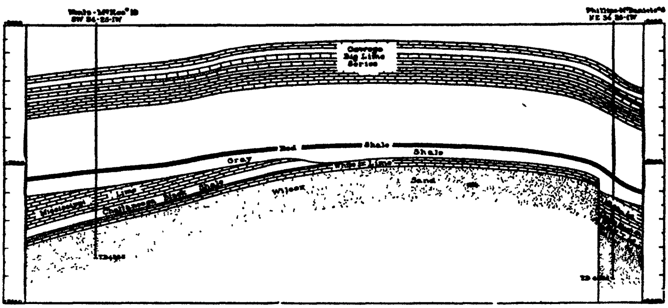

FIG. 112.—Cross-section of Tonkawa field along line *AA* of Fig. 113. Horizontal scale one-half vertical scale. (*After Clark, Bull.* A.A.P.G., **10**, 888, Fig. 2.)

resembles the fields of the Blackwell anticline trend in being a faulted dome. Faulting appears to have taken place after the Mississippi lime was deposited over the whole region, inasmuch as the limestone is present in its full thickness off the domes. It is also possible that the faulting took place in late Ordovician time and that the Mississippian limestone simply overlaps on an Ordovician hill (see Fig. 112). This buried hill and fault is reflected in the surface formations and to a greater degree in the formations lying between the surface and the Viola lime. Figure 113 shows the structure drawn on the lower Hoover sand which is one of the shallow sands. The surface structure is very similar. Note the steep east dip and that the closure amounts to over 110 feet. A map showing the structure on top of the Viola limestone of Ordovician age shows that the steep east dip in the Hoover horizon has become the fault in this horizon. The fault has a throw of 200 feet as a maximum in the SW. ¼ of Sec. 35. The dome with a closure of 110 feet on the Hoover

horizon has become a faulted dome with a closure of over 300 feet.

The producing horizons, as stated above, number 15, but of this number only 4 are of very great importance. They are the

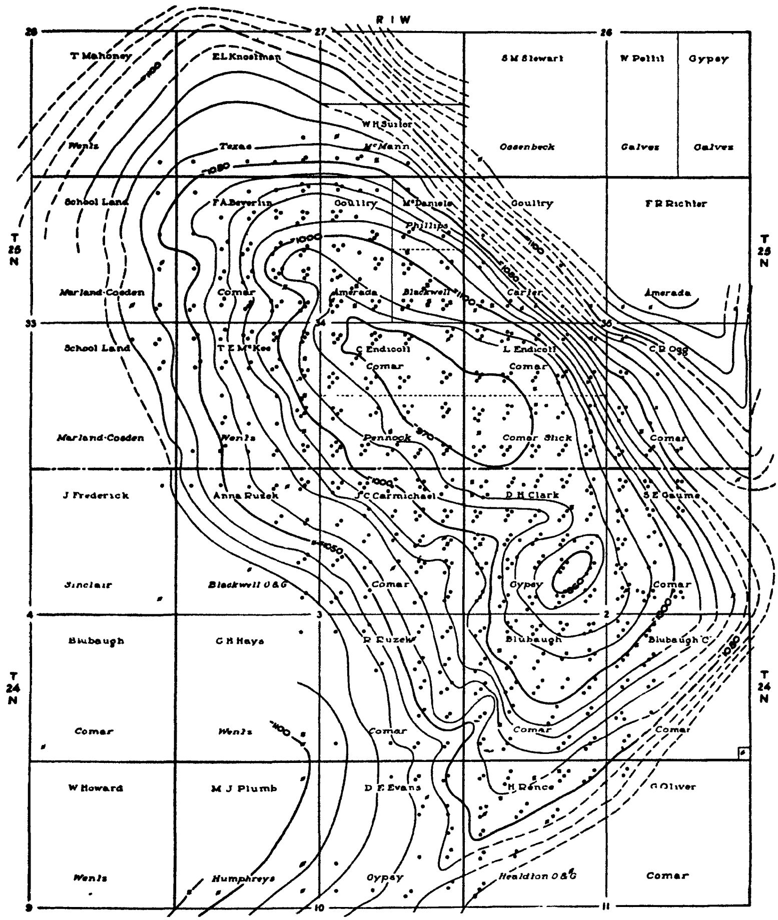

FIG. 113.—The Tonkawa field contoured on the lower Hoover sand. (*After G. C. Clark, Bull.* A.A.P.G., **10**, Pl. XXIX, opp. p. 886.)

Tonkawa, Endicott, Carmichael, and *Wilcox.* The last named is the thickest, 285 feet; the Tonkawa is 100 feet thick; and the other two are quite thin, 5 to 6 feet. The Wilcox sand has shale breaks in it running as high as 30 feet in thickness. There-

fore several pay zones are found. The upper one occurs in the upper 40 feet of sand and the second lies between 60 feet and 120 feet in depth beneath the top. In the lower portion of the Wilcox the proportion of shale is larger and much of this shale is very dark in color suggesting that it may have been the source of the oil. Two wells have found production in the Siliceous lime, however, the amount is not large. Experience seems to show that where both the Siliceous lime and the Wilcox sand produce, *one is likely to be outstanding in production* and the other of small consequence.

In this field, the relation between production and structure is very close (see Fig. 113). This condition seems to be characteristically true of all structures in the western zone of the producing territory. Not only is it true for the deeper horizons as in the eastern zone, but also applies to the shallow producing horizons.

Production Statistics.—In 1929, the state of Oklahoma produced over 252,000,000 barrels of oil. By far the greatest proportion of this total should be credited to northern Oklahoma or the area discussed in the preceding pages. In the last year, the Seminole area in Seminole and Pottawatomie counties contributed the major portion of the total, but the amount secured from other parts of the region was very great when compared to other parts of the country. Some wells in northern Oklahoma have been producing oil for over 30 years and thousands of them for more than 10 years. Probably the largest producer ever drilled in the state is the Gypsy Oil Company well No. 11, Jackson Barnett of S. 5, T. 17 N., R. 7 E., of the Cushing field in western Creek County. It came in on Feb. 7, 1916, at 4,000 barrels per day in the top of the Siliceous lime, but gradually increased to 14,000 barrels per day. Although much of the oil was wasted on account of the lack of storage, it is estimated that this well produced as much or more than the other wonder well of the Gypsy Company (No. 5 on the Shumway lease in the El Dorado district of Kansas) which produced 2,225,000 barrels before it stopped flowing. The Oklahoma well is still producing a small quantity of oil after 12 years of life. The well that gaged the largest single day's production was the No. 33 Noble well of the Carter Oil Company, drilled in S. 21, T. 4 S., R. 2 W., in the Hewitt field of Carter County. This well gaged 14,460 barrels of pipe-line oil in 1 day and 158,000

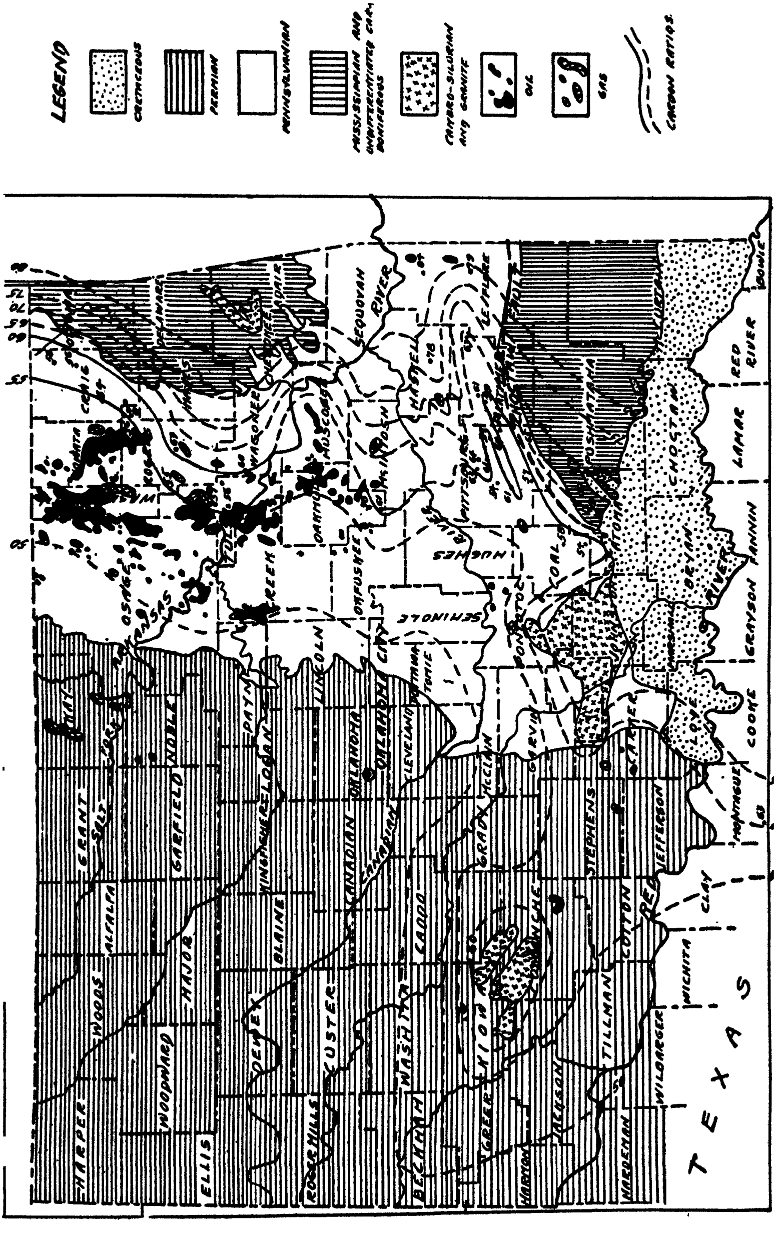

FIG. 114.—Isovolve map of Oklahoma. (*After Fuller. Courtesy of Economic Geology.*)

barrels in 14 days. Some of the largest wells are freak wells. A case in point is the well of the Minnehoma Oil Company drilled in S. 14, T. 26 N., R. 8 E., of Osage County. It was drilled to the Siliceous lime also and came in for an estimated production of well over 10,000 barrels per day. Because no tankage was available, the well was shut in and later when it was reopened there was no more oil. Other wells drilled in every direction from it and as offsets were small or dry.

The gravity of crude oil from northern Oklahoma varies considerably but most of it lies between the limits of 30 and 40°. The average for a large number tested by the Bureau of Mines[1] is about 35.7° Bé. (0.845 specific gravity) which is notably higher than the average figure for the state of Kansas (31.8°). The oil from the Garber field is exceptionally good, much of it averaging 45°, with a gasoline extraction percentage of 52 per cent. In comparison the average sample from the Cushing pool is 39°, and it has a gasoline extraction percentage of 37 per cent. The oil from the Wilcox sand has a tendency to run somewhat higher than the Pennsylvanian oil. In Okmulgee County, Wilcox oil runs from 43 to 44.5° Bé. while the average from the Pennsylvanian sands is about 37° and some from the upper Dutcher is as low as 24°.

Natural Gas.—Gas was found in nearly every one of the important oil-producing areas in greater or less quantities. Inasmuch as it was needed for drilling and other lease purposes, the exact amount produced is not known. But it is estimated that the amount in 1925 was not far from 250,000,000 cubic feet. The state ranks first in the production of natural gas, with California second, and West Virginia third. The most important gas-producing areas are Chickasha, Blackwell, Quinton, Poteau, Burbank, Sayre, Ada, Walters, Hogshooter. Some of these pools lie within the carbon ratio belts (see Fig. 114) which show more than 60 per cent fixed carbon.[2]

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CHAPTER VI

THE OUACHITA-AMARILLO MOUNTAIN PROVINCE

In southern Oklahoma, north central Texas, and the Panhandle of Texas, there are groups of oil fields which are clearly related to a group of tectonic elements limited on the east by the Ouachita and on the west by the Amarillo Mountains. The oil fields in this province extend from east central Marshall County, Oklahoma, to Oldham County in Texas. South of the Red river, the oil and gas fields in Clay, Wichita, Wilbarger, and Foard counties also belong to this province (see Figs. 115 and 133).

Tectonic Elements.—The major tectonic elements are seven in number and are shown in Fig. 83, p. 222. Five are positive elements—the Ouachita, Arbuckle, Wichita, and Amarillo Mountains, and the Red River uplift while two are negative elements—the Red River syncline and the Anadarko basin. The positive elements will be described first.

The *Ouachita Mountains* involve an area 200 miles long and 50 miles wide extending from Atoka, Okla., to Little Rock, Ark. They have been studied and described by Honess, Miser, and Purdue,[1] but the stratigraphy is so different from that of adjacent areas and the structure is so complicated that much work still needs to be done before their geological history will be entirely clear. When this is accomplished, it may develop that the Ouachitas belong to a different tectonic unit—one whose history is inseparably bound up with that of Llanoris—and that it should be included in the Gulf Embayment province. For the present, however, it will be included in this province.

The structure of the Oklahoma portion of the Ouachitas is described by Honess in considerable detail. He summarizes the principal facts as follows:

(1) A belt of thrust folding and normal faulting with prevailing dip of the strata to the north at angles of from 45 to 60 degrees; (2) a belt of thrust folding and thrust faulting, with prevailing dip of the strata toward the south at angles of from 45 to 90 degrees; (3) a belt of gentle

[1] See Bibliography.

folding in which are developed normal anticlines and synclines with strata dipping in both directions, north and south at angles of from 15 to 45 degrees.

Further facts regarding the structure of the mountains can be appreciated better after the stratigraphic sequence has been examined.

In the table below, is indicated the correlation of the formations found in the Ouachita Mountains according to the most able authorities. For comparison, the names of the formations in the Arbuckles and the Ozarks have been added, not with the idea of trying to indicate exact time equivalence, but rather to enable the reader to compare formations of approximately equal

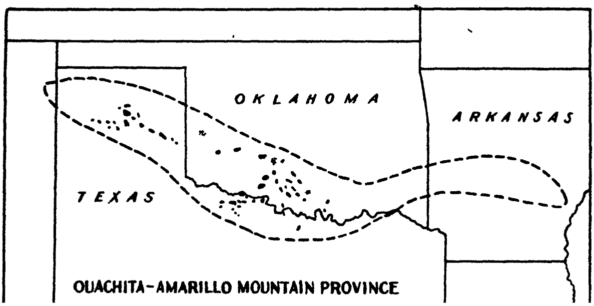

FIG. 115.—Ouachita-Amarillo Mountain province. Solid black indicates oil pools, stippled areas gas only. Province outlined by dashes.

age.[1] It will be noted that the oldest formation is called the "Collier shale." This is believed to be of Cambrian age largely on the basis of its position in the column. It is not inconceivable that this formation may be of Proterozoic age and may in time be found to correspond to the schists found east of the Balcones fault in Texas. The Crystal Mountain formation, likewise, has been assigned to the Cambrian without fossil evidence. It may be of nearly the same age as the Reagan sandstone. The Mazarn shale carries graptolites of Beekmantown age and is therefore comparable, at least in part, to the upper part of the Arbuckle limestone. The Blakely and Womble sandstones occupy the same position in the section as rocks described by Miser from Arkansas in which graptolites of Beekmantown and Normans-

[1] For the most detailed and recent correlation table see Ulrich, *Okla. Geol. Survey Bull.* 45.

kill age have been found. The poorly preserved graptolites from the Bigfork chert have no direct correlatives in this country, but are thought to correspond most closely to Mohawkian forms. In the Polk Creek shale of Arkansas, as well as Oklahoma, graptolites are plentiful and they indicate the top of the Ordovician. The Blaylock sandstone has supplied some graptolites in Arkansas, which indicate a basal Silurian horizon (again on the basis

CORRELATION TABLE—OUACHITA-ARBUCKLE DISTRICT

	Ouachita Mountains[1]	Correlation[2]	Arbuckle Mountains[3]	Ozarks[4]
Pennsylvanian	Atoka sandstone	Pennsylvanian	Atoka sandstone	Winslow
	Johns Valley shale	Pennsylvanian		Morrow
	Jackfork sandstone	Pennsylvanian	Wapanucka	
Mississippian	Stanley shale	Mississippian	Caney Sycamore limestone	Moorefield, etc. Boone limestone
Devonian	Arkansas Novaculite (upper and middle)	Chattanooga	Woodford	Chattanooga
	Arkansas Novaculite (lower)	Onondaga Oriskany	Hunton (upper)	Penters chert
Silurian	Missouri Mountain shale			Lafferty limestone
	Blaylock sandstone	Basal Silurian	Hunton (lower)	St. Clair limestone Brassfield limestone
Ordovician	Polk Creek shale	Upper Ordovician	Sylvan shale	Cason shale
			Viola (upper)	Fernvale limestone
	Bigfork Chert	Mohawkian	Viola (middle) Viola (lower)	Kimmswick limestone Plattin limestone
	Womble shale Blakely sandstone	Normanskill	Simpson	Joachim limestone St. Peter sandstone
	Mazarn shale	Beekmantown	Arbuckle limestone (middle and upper)	Cotter limestone, etc.
Cambrian			Arbuckle (lower)	Ozarkian limestone
	Crystal Mountain	Cambrian (?)	Reagan sandstone	Lamotte sandstone
	Collier shale	Cambrian(?)	Missing(?)	Missing(?)
			Granite	Granite

[1] HONESS, PURDUE, and MISER.
[2] ULRICH, SCHUCHERT and WHITE.
[3] TAFF, ULRICH, and REEDS.
[4] MISER, PURDUE, and ULRICH.
(See especially *U.S. Geol. Survey Bull.* 715, and 808 also *Folio* No. 202 and 215; *Okla. Geol. Survey Bull.* 32, 44 and 45.)

of similar forms found in Scotland). No fossils have been found in the Missouri Mountain shale. The Arkansas Novaculite is separated into at least two parts on paleontological evidence. The lower portion contains early Devonian forms and the middle portion undoubted Woodford or Chattanooga forms. Since the formation consists of black shales and partly of black cherts, it corresponds very closely to the Woodford of the Arbuckles and the Chattanooga of the Ozarks. Indeed, this formation is about the only one in the section which shows a striking lithologic resemblance to rocks in adjacent areas.

The formations above the Novaculite have created much difficulty, and no general agreement has been reached as to their precise position in the column. Ulrich believes that the Stanley shale may be Mississippian, but that the Jackfork should be placed into the Pennsylvanian. Miser, on the other hand, would prefer to place both into the Mississippian. The fossil evidence is meager and inconclusive but the burden of proof seems to rest on the age of the Caney shale. Dark shales referred to the Caney have been found both in the Ouachitas and the Arbuckles. The Caney shale in the Arbuckles carries a fauna of Mississippian age, but the Ouachita Caney appears to have no indigenous fauna. Instead it carries a fauna imbedded in ice-transported boulders, some of which are apparently fragments of the Arbuckle Caney shale. Other boulders are of Ordovician, Silurian, and even of Wapanucka age. Miser[1] believes that the Arbuckle and the Ouachita Caney shales are one and the same.

Returning now to the question of structure, and especially to periods of diastrophism during which the present structural features were produced, evidence is found in the stratigraphic record of at least three such periods. An unconformity above the Mazarn shale, together with the coarseness of the succeeding Blakely and Womble sandstones, suggests orogenic movements. This is further strengthened by the fact that the Mazarn is intricately folded and crumpled, showing that it probably suffered deformation a number of times. Similarly, the unconformity at the top of the Ordovician, coupled with the fact that the oldest Silurian (the Blaylock) consists of coarse, near-shore materials, also suggests diastrophic movements. The abrupt differences in thickness of this formation as noted by Miser in Arkansas lend further support to this view. Finally, both Miser and Honess report intense crumpling of beds in the Ordovician formations (including the resistant Bigfork chert), such that it is quite hopeless to decipher the true structure of these formations. These facts make it appear probable that orogenic movements took place a number of times in the Ouachitas and probably reached a first climax after the close of the Ordovician period.[2] The structure sections in Miser's report of the Hot Springs district as well as the structure sections in Honess' report are almost entirely based upon the deformation revealed by the Arkansas

[1] See *Okla. Bull.* 44, p. 23.

[2] See MISER, *Folio* 215, 6, 3rd. col., and HONESS, *Bull.* 32, p. 214.

Novaculite; and the parallelism of beds shown is *entirely diagrammatic* below that horizon. They *do not indicate conformity,* therefore, below the Devonian. The disconformity of the Arkansas Novaculite structure as compared with the overlying Stanley shale makes it appear probable that renewed diastrophism is indicated. Certainly the coarseness of the Hot Springs sandstone which appears in some places between the two would testify to great changes in elevation within the region.

It is not unreasonable to suppose that the Ouachita Mountains were deformed during approximately the same periods of time and probably in the same manner as the southern Appalachians. For this region, there is no greater authority than Arthur Keith, whose field work, extending over many years, enabled him to decipher and describe the details of the very obscure Paleozoic diastrophism.[1] His maps indicate three belts of structural types: (1) a belt of shear faulting involving eo-Paleozoic rocks only; (2) a belt of thrust faulting and thrust folding involving Cambrian and Ordovician rocks with dips toward the southeast; and (3) a broad zone of symmetrical anticlines and synclines in which there has been some faulting and also considerable overthrusting from the other two zones lying farther southeast.

A careful study of the maps published by Miser and Honess reveals some striking similarities to the conditions in the southern Appalachians. This is revealed partly in the distribution of the formations and becomes more noticeable when they are grouped into eo-, meso-, and neo-Paleozoic. It is also revealed in the nature and location of the faults, as well as the position of unconformities and the lithology of the formations. From these considerations the impression is gained that the old land mass (Llanoris ?) rose while a narrow foredeep sank and accumulated Cambrian and Ordovician sediments. During this period, and especially at the end of it, low angle shear faulting took place which transferred some of the sediments and some of the old land mass to the north. In a new foredeep, farther north, Silurian and Devonian sediments accumulated, which, together with the older sediments, were deformed by thrust folding and faulting from the south. New land masses were thus created, partly within the old foredeeps, and these furnished the materials for the very thick and coarse deltaic deposits of Stanley and

[1] *U. S. Geol. Survey, Folio* 151 and *Bull.* Geol. Soc. Am., 1921.

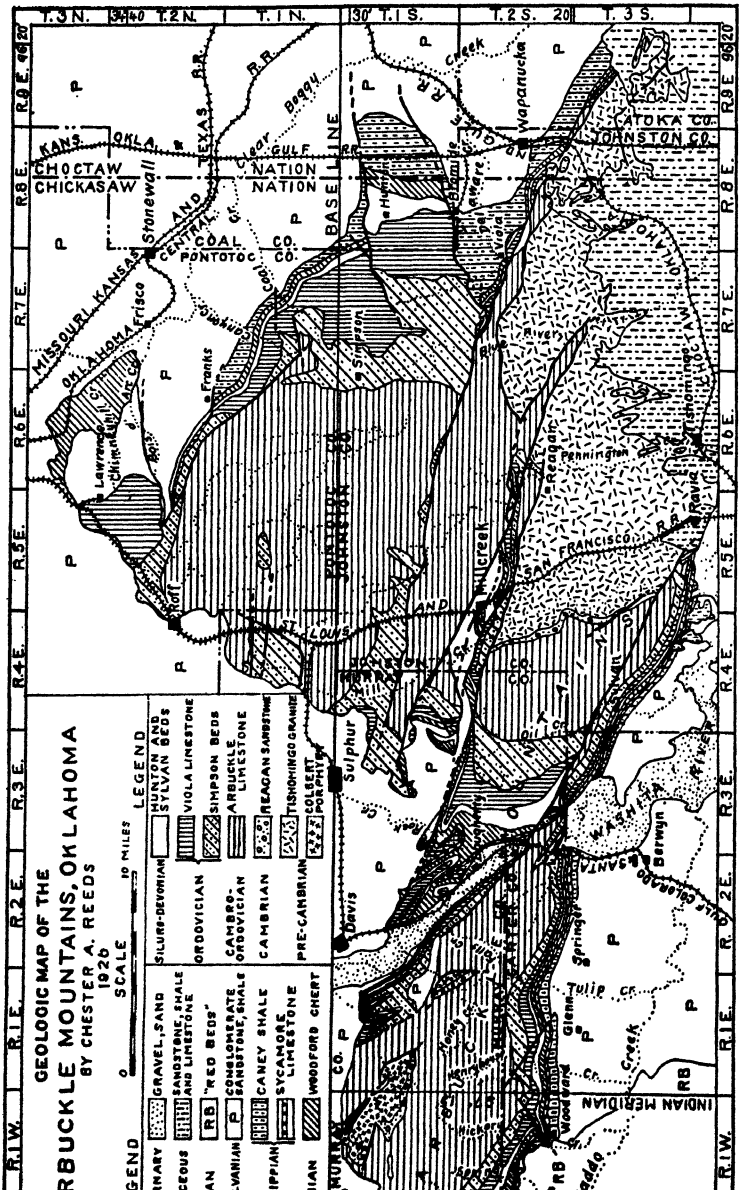

FIG. 116.—Geologic map of the Arbuckle Mountains. (*After Reeds, Okla. Geol. Survey, Circ.* 14, p. 8, Fig. 6.)

Jackfork time. Finally, all sediments were again compressed in early Pennsylvanian time.

The Arbuckle Mountains.—The Arbuckle Mountains begin about 20 miles west of the Ouachita Mountains in northwestern Atoka County and extend to the western edge of Murray County, thus including most of Johnston and a large portion of Pontotoc Counties—an area 60 miles long and 40 miles wide. The highest point is only 1,350 feet above sea level and the lowest is 750 feet above the same datum. They really constitute a dissected plateau in which the roots of a former majestic mountain area are exposed. The strata which are involved range in age from upper Cambrian through Ordovician, Silurian, Devonian, and Mississippian into Pennsylvanian (see Fig. 116).

The Arbuckle Mountains are very accessible and have been thoroughly studied by many geologists. There are a number of very good reports on the structural conditions as well as on the stratigraphic conditions in this part of Oklahoma. The central portion of the Arbuckle Mountains is made up of pre-Cambrian granite and older Paleozoic sediments, chiefly of Ordovician age. The rocks are highly folded and faulted and the bedding planes are inclined at steep angles. The main axis of the mountains trends northwest and southeast and lies in the southern part of Murray County below Dougherty. This has been called the "Arbuckle anticline." Six miles south of this anticline lies a shallow syncline called the "Glenn syncline," and one mile south of this is the Caddo anticline. Passing through the town of Ardmore is a well-defined syncline called the "Ardmore syncline" or "Ardmore basin," and a few miles south of it is another anticline which is also well known because of oil fields associated with it—the Criner Hills. In the Criner Hills, the Ordovician strata appear at the surface, but in the intervening area a great thickness of Pennsylvanian strata crop out with some Permian rocks. Figure 117 will illustrate the structural conditions somewhat generalized between the Arbuckle anticline and the Criner Hills with an additional picture of the conditions farther southwest to include the Hewitt oil field and the famous Healdton field. The close of the Ordovician period in many parts of our continent was marked by very profound diastrophic movements as, for example, the Taconic Mountains, and the early thrust faulting in the southern Appalachians, as described by Keith. As will be shown later, the Wichita Mountains farther west show

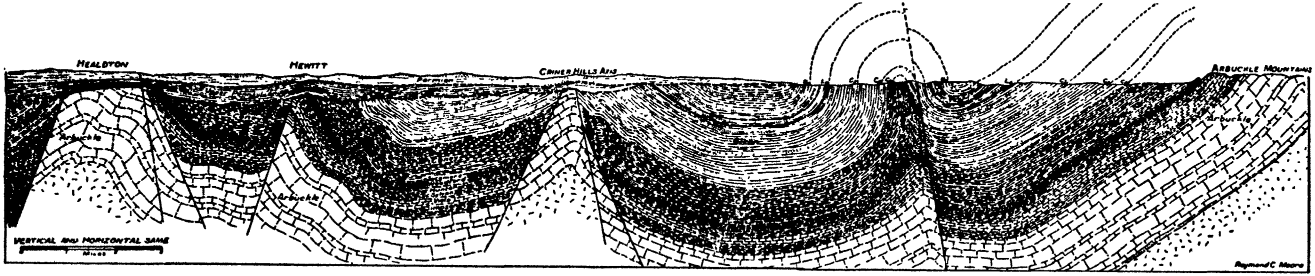

FIG. 117.—Geologic section from Healdton to the Arbuckle Mountains. (*After Moore, Bull.* A.A.P.G., **5**, 43. Pl. III.)

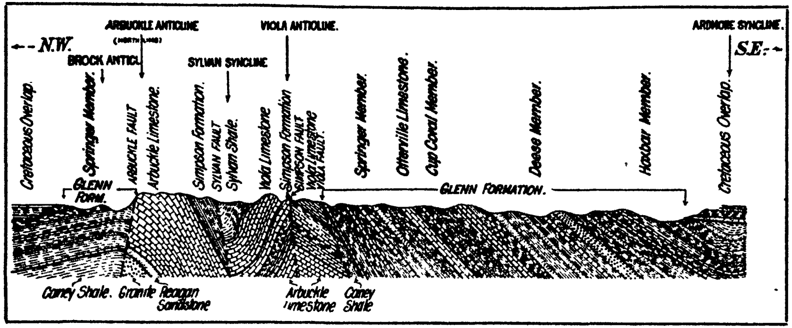

FIG. 118.—Cross-section from northwest to southeast across the Criner Hills and the Glenn formation surrounding these hills. (*After Goldston, Bull.* A.A.P.-G., **6**, 17, Pl. IV.)

that great disturbance took place there at the close of the Ordovician period. Hence we are justified in assuming that in the Arbuckle region also the first, and possibly very profound, diastrophic movements took place at the close of the Ordovician period. Figure 118, which is taken from Goldston's report on the Glenn formation of southern Oklahoma, suggests this. It is a cross-section of the Criner Hills uplift on a larger scale. The central area consists of a number of parallel northwest-southeast ridges, separated by narrow valleys, the limestones, Arbuckle, Viola etc., forming the ridges and the softer formations, Sylvan, Simpson, etc., forming the valleys. The sediments of the Glenn formation surround this central mass assuming the shape of an anticlinorium which has been intensely faulted on the west side and overturned in places on the east side. The dip of the rock varies from 55 to 70 degrees on the east, from 25 to 50 degrees on the north side and from 10 to 20 degrees on the west side. In general, the Glenn formation dips in the same direction as the older rocks but with a *different* angle and where the faults and overturned folds are located the *direction does not coincide.*

Again from another line of evidence the same conclusion appears to force itself upon us. When the structure of a number of the oil fields in this province is studied in detail, it is noted that in many cases the Glenn formation of Pennsylvanian age lies directly upon rocks of Ordovician age which in most cases show *more severe deformation* than the former.

The Wichita Mountains.—The Wichita Mountains are located in northwestern Comanche County with small outlying portions reaching over into southern Caddo, eastern Kiowa, and especially central Kiowa counties. They occupy an area 40 miles long and 20 miles wide. The central mass, which entitles it to be called a "mountain mass," consists of igneous rock. This central core is surrounded on nearly every side by Permian strata which have but a slight inclination away from the granite. At a few places, Ordovician strata have been found which in every case are standing at high angles and give every indication of having been subjected to deforming movements on a vast scale. Deep drilling in the vicinity of the mountains and especially in the saddle between the Wichitas and the Arbuckles has revealed similar buried mountains of folded and faulted Ordovician rocks.

In the 60 miles between the Arbuckle and the Wichita Mountains (including parts of western Carter, eastern Comanche, and

all of Stephens counties) no rocks of Silurian, Devonian, or Mississippian age have been found, the drill in each case passing from the Pennsylvanian or Permian directly into strata of Ordovician age. This indicates very clearly that the Wichita Mountains and a large section of the state to the east and south were affected by diastrophic movements some time before Pennsylvanian time and probably long before that time. The most logical time to set for the first period of faulting and folding is the close of the Ordovician. This coincides with evidence of similar movements in other parts of the continent and also allows sufficient time to elapse so that the enormous amount of erosion indicated by the complete absence of the Viola and Simpson from the tops of most of the buried hills in Stephens County, can be accounted for. Hence, the conclusion is that the Wichita Mountains date from the close of the Ordovician period. Nevertheless, subsequent movements took place along the same lines of weakness and involved the same areas. These periods seem to coincide with the periods which affected the Arbuckles, farther east, and the Ouachitas. There is evidence of important deformation after middle Pennsylvanian time and probably also in Permian time. In the Wichita Mountain area the Permian movements are proved by the slight discordance in dip between the lower Permian (Wichita-Clear Fork) and the upper Permian (Duncan) as well as by the sharp fold in the Duncan sandstone at Cruce and to the northwest of that point in Comanche County. The surface rocks of the Wichita-Clear Fork division also show numerous gentle folds. Some of these folds are above buried hills, but many buried hills are probably not reflected at all in the surface dips.

The Amarillo Mountains.—In 1918, gas was found in a well drilled in the Panhandle of Texas and three years later oil was discovered there. Subsequent work by many petroleum geologists has revealed the existence of a *buried mountain* of *granite* flanked with huge talus cones of detrital material and capped with limestone of possible Pennsylvanian and Permian age. The buried mountain range can be traced from Oldham County in the western part of the Panhandle to Wheeler County in the eastern part of the Panhandle and, indeed, beyond that point into Oklahoma, practically to the Wichita Mountains.

It appears that the Wichita Mountains are the last small remnant of a much larger mountain range which at the close of the

Ordovician period extended from Carter County, Oklahoma, westward as far as eastern New Mexico, a distance of 350 miles. This mountain range may have had Ordovician strata above it, but they were almost entirely removed by erosion during the long interval of time that the mountains were above sea level. They do not show any strata belonging to the Silurian, Devonian, or Mississippian systems, and, the Pennsylvanian system, if present in the Amarillo Mountains, is probably very thin. The elevation of the Amarillo Mountains is over 1,500 feet in many places and the length of the range is over 150 miles with a width of about 40 miles.

The Amarillo Mountains, like the Wichita Mountains, were very probably formed at the close of the Ordovician period. Subsequently, movement probably took place again at intervals chiefly along a line of faulting which marks the northern edge of the granite core. Movement along this fault zone as late as Permian time is indicated by a study of the Beckham County wells made by Frank Gouin.[1]

The presence of this fault was first suggested to Gouin by the occurrence of the Blain gypsum in the Martin well in S. 31, T. 9 N., R. 23 W. at an abnormally low elevation. He then traced the fault on the surface by means of a large artesian spring as a starting point and careful inquiry among farmers about depth and character of water wells. This investigation brought out the fact that water wells on the south or upthrow side of the fault were 40 to 60 feet deep and highly charged with sulphate salts whereas the water wells on the north or downthrow side were 100 to 300 feet in depth and remarkably free from salts. The amount of throw of this fault is from 300 to 500 feet.

Anadarko Basin.—The Anadarko basin was described by Gould in 1924[1] as a large synclinal basin, the southeastern end of which lies in northeastern Stephens County a few miles northwest of the west end of the Arbuckle Mountains. It trends nearly northwesterly from there to Beckham and Roger Mills counties in Oklahoma and then crosses the border into the Panhandle of Texas where it continues for a distance of another 150 miles, giving it a total length of over 300 miles. This basin is really a geosyncline formed in late Pennsylvanian time by renewed downfaulting of the north side of the Amarillo-Wichita Mountain chain. It remained a geosynclinal trough during

[1] See Bibliography.

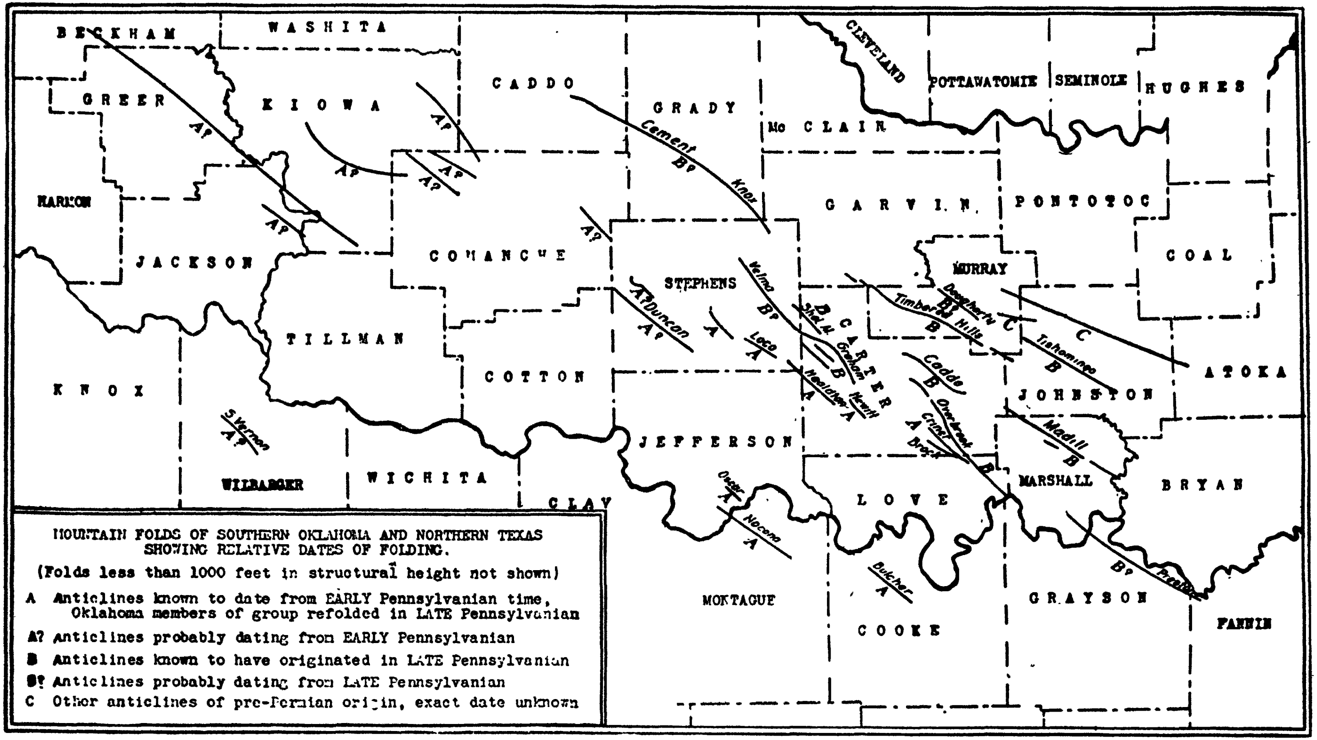

FIG. 119.—Map of the southern Oklahoma district showing structural trends. (*After Tomlinson, Okla. Geol. Survey Bull. 46.*)

Permian time and in it were deposited at least 2,000 feet of Permian sediments besides an unknown amount of late Pennsylvanian materials. The preliminary map on the base of the Enid formation made by Greene and Toomey[1] shows the axis of the Anadarko basin up nicely. It reveals the fact that the dip off the Amarillo-Wichita Mountain chain in central Beckham County is very steep. In this report, Greene mentions the deep well near Canute in northwestern Washita County which entered granite wash at 5,070 feet, indicating that the Anadarko trough is at least as deep as 5,000 feet.

Red River Uplift and Syncline.—In the area lying south of the mountains the regional dip away from the Wichita and possibly Arbuckle Mountains may be said to approximate a direction toward the south or southwest. In Texas, on the other hand, the regional dip is to the northwest. We are led to expect, therefore, a syncline of substantial proportions somewhere in the vicinity of the Red River with an axis plunging toward the west.

The Red River uplift or anticline is now pretty well established according to the data published by Fuqua and Thompson. Hager described it in the *Oil and Gas Journal* for May, 1919[2] on the basis of some deep wells which had encountered the Ordovician strata in Clay and Wichita counties and some which had entered granite. It seems to extend from Cooke County on the east to Foard County on the west (see Figs. 130 and 170). In a recent article by Cheney it is called the "Electra arch."[3]

Stratigraphy.—The rock succession in the Ouachita-Amarillo Mountain province is similar to that for northern Oklahoma in many respects, and to that of northern Texas in some details. For certain parts of the generalized section, the excellent descriptions of Taff, who described the rocks in the Arbuckle Mountain region, are used; for some parts, the names first proposed by Morgan in his work on the Stonewall quadrangle are used. For the subdivision of the Pennsylvanian, the works of Goldston and Tomlinson are chiefly relied on; and for the Permian subdivisions, the names proposed by Gould are used. In this part of Oklahoma interest in the Cretaceous rocks begins, for they form a cover over a small portion of the oil district (see Fig. 89 on p. 231).

[1] See Bibliography, Pl. II.

[2] *Oil Gas Jour.*, **18**, 64–65, 1919.

[3] *Bull.* A.A.P.G., **13**, 583.

System	Series / Group	Formation	Thick'ss in feet	Character of Formations
CRETACEOUS	GULF SERIES	Woodbine sand	50	Soft yellow to brown sandstone with large quantities of ferruginous segregations
		UNCONFORMITY		
COMANCHEAN	WASHITA GROUP	Grayson marl	30	Yellow to gray calcareous marl; lime nodules
		Bennington limestone		Massive brown yellow limestone.
		Bokchito formation — Pawpaw sandy member	50	Yellow to gray sandstone with calcareous shales and numerous ferruginous lenses.
		"Quarry" limestone		
		Bokchito formation — Weno clay member	100	Dark gray shaly clay with thin lenses and layers of soft yellow sand.
		"Ostrea carinata bed"		
		Bokchito formation — Denton clay member	45-60	Brownish yellow clay. Thinly laminated brown sandstone with ripple marks.
		Fort Worth limestone	40-50	Alternating beds of white limestone and bluish gray shale.
		Duck Creek formation	65	Blue-gray calcareous shale
	FREDERICKSBURG GROUP		35	Large ammonite horizon (Schloenbachia brazoense) Alternating beds of blue-gray shale & limestone
		Kiamichi clay	30-40	Indurated shell breccia composed of Gryphea navia. Greenish yellow clay.
		Goodland limestone	15-25	Massive white limestone
	TRINITY GROUP	Trinity sand	400-700	Fine white to yellow pack sand with occasional lentils of red and blue shale. Basal conglomerate of quartz pebbles.
		UNCONFORMITY		
		PALEOZOIC		

Bess Mills-Bullard

FIG. 120.—Section of rocks exposed in Marshall County. (*After Bullard, Okla. Geol. Survey Bull.* 39, p. 19, Fig. 4.)

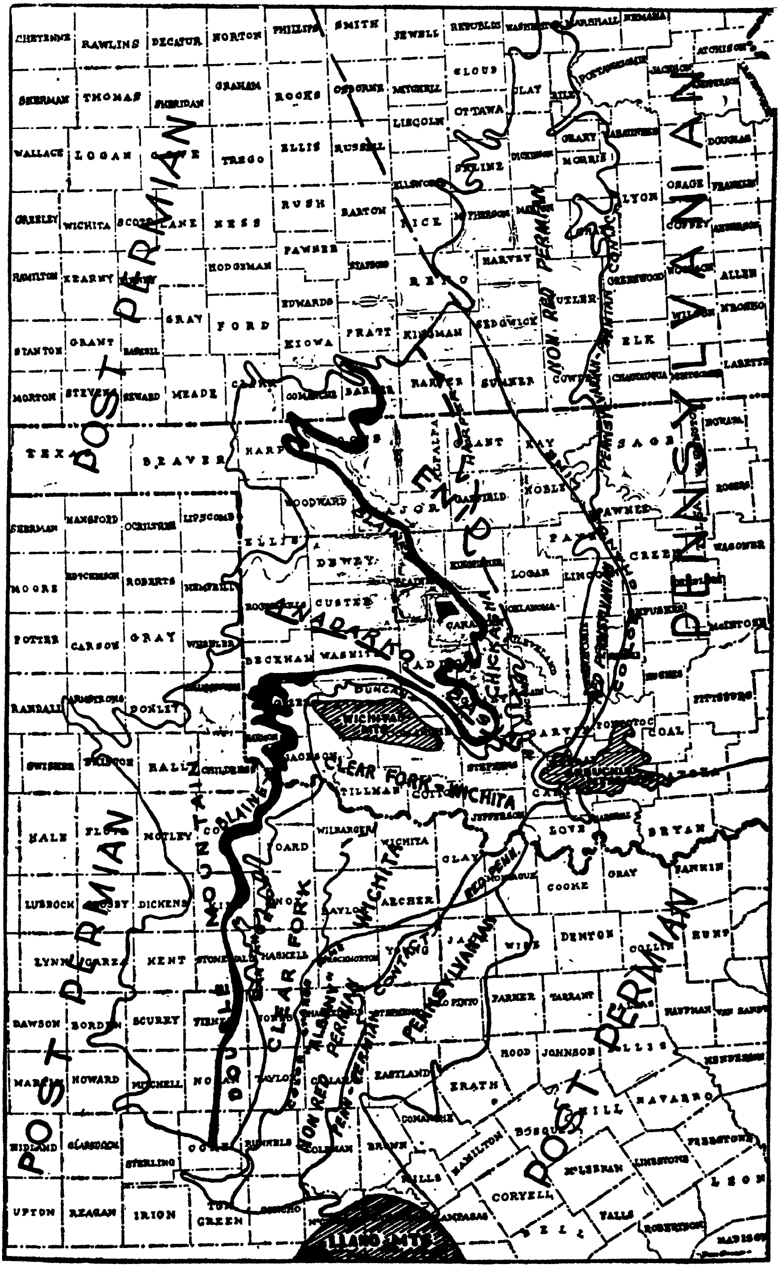

FIG. 121.—Map of Permian rocks of Kansas, Oklahoma and northern Texas. (*After Gould, Bull.* A.A.P.G., **10**, 145, Fig. 1.)

Figure 120 shows the Comanchean and Cretaceous rocks exposed in Marshall County where the only field is located in which oil is produced from Comanchean strata, the Madill pool. The Comanchean is divided as it is in Texas into the Trinity, Fredericksburg, and Washita series. The upper Cretaceous is represented only by a portion of the Gulf series—the Woodbine sand. In the Madill pool oil is found at a depth of 420 feet in the basal portion of the Trinity sand. This sand was named by Hill in 1888 from the Trinity River of central Texas, where it is typically exposed. In southern Oklahoma it is a fine, white to yellow, unconsolidated sand which occurs in massive layers 40 to 50 feet thick and separated by lentils of clay. The clay varies in color from yellow to purple and is frequently mottled. The other members of the Cretaceous and Comanchean section will not be described further at this point, because of their relative lack of economic importance in the area under discussion.

PERMIAN FORMATIONS OF OKLAHOMA AND TEXAS[1]

Texas	Oklahoma	
Double Mountain	Quartermaster Cloud Chief Day Creek Whitehorse Dog Creek Blaine Chickasha Duncan	Woodward series
Clear Fork	Hennessey Garber	Enid series
Wichita (Albany)	Wellington Stillwater	

[1] *After Gould, Circ.* 13, p. 9 (see Bibliography)

The correlation table of Permian formations in Oklahoma and Texas given above will enable the reader to see the succession of the rocks of this period and their relationship to each other and to those of Texas. As the map (Fig. 121) shows, the Permian rocks of Oklahoma cover a very large part of the state and are particularly abundant in the province with which we are dealing. No doubt the most important member in the system, from the standpoint of surface and subsurface correlation, is the *Duncan*

sandstone found at the base of the Woodward series. It is now known to be the same as the *San Angelo* sandstone in Texas, which is the basal member of the Double Mountain series. In southwestern Oklahoma, the Duncan is about 100 feet thick and lies from 275 to 350 feet below the Blaine gypsum which is next to it in value as a key horizon. In Stephens and Garvin counties at the east end of the Anadarko basin, the Duncan is somewhat thicker, having been found to be as much as 250 feet thick. This would seem to indicate that the sediments which formed the sandstone came from the Arbuckle Mountains and reached westward up the Anadarko basin and along the old Wichita-Amarillo Mountain chain as far as Wheeler County (in the Panhandle of Texas). There the sandstone appears to be replaced by red shale or by salt layers. The *Chickasha* formation is 275 to 350 feet thick in Beckham County and consists of red shale with some gypsum and limestone. To the west it cannot be differentiated. Farther east in Caddo and Grady counties it is subdivided into three members. The upper Chickasha is 45 to 80 feet thick and consists of a series of deep red to purple mudstone conglomerate lenses, separated by fine-grained, uncemented sand. The middle Chickasha is 40 to 50 feet thick and consists entirely of pink unconsolidated sand. The lower Chickasha is 50 to 100 feet thick and consists of massive dark-red mudstone lenses with some sandy shale. All of these divisions become more shaly and gypsiferous toward the north and west and more conglomeratic toward the Arbuckle Mountains region.

The *Blaine gypsum* is a very valuable key horizon and may be traced from Barber County, Kansas (see Fig. 121) southeast to the northern part of Stephens County where it turns west into the Anadarko basin and around the Wichita Mountains. Underground it is recognized in the logs of wells drilled in the Panhandle of Texas as well as over all of western Oklahoma. At its type locality, it has an average thickness of 75 feet and consists of three heavy gypsum layers separated by red clay shales. At other places, it is not so well defined, consisting of gypsiferous shales only, without definitely determinable top or base. In the eastern end of the Anadarko basin some sandstones appear in it.

The oil and gas fields of the Panhandle district are located above this formation and as a rule it is to be noted in the well logs. In Carson County, for example, it is 220 feet thick and in Potter County it is 340 feet thick. Farther south, it becomes

much thicker, reaching a thickness of 700 or 800 feet, some of this being logged as lime and salt by the drillers.

Below the Duncan sandstone, the rock section of southern Oklahoma shows brick-red shales with a few thin, grey shales and thin sandstones, also of red and grey color. They are the equivalent of the *Wichita* and *Clear Fork* formations in Texas and of the *Hennessey, Garber, Wellington,* and *Stillwater* formations of Oklahoma. The Oklahoma formations were named from type localities which lie at a considerable distance from southern Oklahoma and the lithologic character of the formations has changed so greatly in that distance that they are not distinguishable. Geologists working in the southern counties have therefore adopted the practice of dividing the Enid series of rocks into "units" to which they have assigned numbers. In Garvin County this series approximates 1,100 feet in thickness, and Dott has divided it into eight fairly distinct lithologic units on the basis of the predominance of either sandstone or shale. He states that he was able to trace some of the sandstones considerable distances. In Stephens County, the Enid series consists of 600 to 2,000 feet of brick-red shales with some sandstones and thin, grey shale zones. In Beckham County, the Enid series is divided into two parts by Gouin and named according to Texas nomenclature. The upper or Clear Fork division consists almost entirely of red shales with a thickness of 1,420 feet near the old mountain axis in the southern part of the county and 2,170 feet in the northern part of the county. Three salt horizons are present in it; one just below the Blaine, another 300 feet below it and a third 500 feet below the Blaine. He includes in his Clear Fork about 300 feet of strata which are the equivalent of the Duncan and Chickasha.

The *Wichita-Albany* rocks in Beckham County consist of grey shales and anhydrite 700 feet thick. About two-thirds of the formation is gray shale and one-third anhydrite. Farther west in the Texas Panhandle the anhydrite thickens at the expense of the shale and the proportions are reversed. This series of rocks is called the "Big Lime" in the Amarillo district of the Panhandle and is usually found at a depth of about 2,100 feet. Besides anhydrite and shale it also contains some dolomite and much limestone, from which fact it derives its name. It is only 400 feet thick over the crest of the Amarillo Mountains, but thickens rapidly on the flanks to 800 feet and some distance away from the granite is over 1,800 feet thick.

Pennsylvanian Rocks.—The Pennyslvanian rocks of the province under consideration consist of shales, sandstones, and occasional thin limestones. They change so quickly in a horizontal direction and the thickness changes so greatly from one part of the area to another that it is practically impossible to make any correlations of the members defined at any one place. A great deal of confusion has arisen in the nomenclature as a result of this condition and much of the confusion still exists, despite the fact that many geologists have been working in southern Oklahoma and have tried to bring order out of chaos.

Perhaps the best section of the Pennsylvanian rocks in the region is to be found on the flanks of the Arbuckle Mountains. Taff described portions of this area in folios 98 etc., and gave names to some Pennsylvanian formations. The most important one of these is the *Glenn* formation. This formation was described very exhaustively by Goldston,[1] in 1922, in the Ardmore basin between the Arbuckle anticline and the Criner Hills. He states that it has a thickness of 15,000 to 18,000 feet in this region and consists of shales, sandstones, limestones, and conglomerates. Tomlinson[2] has divided it into four formations. These are the Springer, Dornick Hills, Deese, and Hoxbar formations. The Glenn formation seems to be very bituminous at places, many of the sandstones showing considerable amounts of asphalt formed by the evaporation of fluid hydrocarbons. It is not unreasonable to suppose that much of the petroleum found in southern Oklahoma originated in these beds and was largely stored in them.

West of the Arbuckle Mountains rocks similar to the Glenn formation are found in wells, but no differentiation into members has been possible. In Garvin County and north of the Arbuckles rocks have been found below the Permian nearly 3,000 feet thick which are equivalent to the Glenn formation. In Stephens County a number of wells have penetrated the Glenn formation and quite a few well cuttings have indicated that the Glenn is present with a considerable thickness. Gouin believes that the amount of Glenn present at any one place depends upon the relation the area has to the general highs or buried hills in the county. Rocks of Glenn age are probably absent or very

[1] See Bibliography.
[2] *Okla. Geol. Surv. Bull.* 46.

thin in southwestern Oklahoma and also appear to be missing in the Panhandle.

Above the rocks of lower Pennsylvanian age, other rocks, belonging to the same system but apparently much younger, are found. On the Hunton arch, for example, in northern Pontotoc and southern Pottawatomie counties, a thin layer of fossiliferous shale overlies the Glenn, or, where it is absent, the older Paleozoic rocks. This has been correlated with the Ada formation, first named by Morgan in his description of the Stonewall quadrangle. Conformably, overlying this shale are beds of the Pontotoc terrane. In the succeeding table taken from Dott's report on Garvin County, the relations of Pennsylvanian strata south and north of the Arbuckles are shown to each other and to formations in northern Oklahoma.

SUBSURFACE STRATIGRAPHY OF GARVIN COUNTY WITH CORRELATIONS

<table>
<tr><th>System</th><th>Northern Oklahoma</th><th>Garvin County and vicinity</th><th colspan="2">Carter County</th></tr>
<tr><td>Permian</td><td>Enid</td><td>Enid</td><td colspan="2">Enid</td></tr>
<tr><td rowspan="10">Pennsylvanian</td><td>Wabaunsee</td><td>Pontotoc
Ada</td><td colspan="2">Pontotoc</td></tr>
<tr><td>Shawnee</td><td>Vamoosa</td><td colspan="2">Break(?)</td></tr>
<tr><td>Douglas</td><td>Break(?)</td><td colspan="2">Break(?)</td></tr>
<tr><td>Lansing</td><td>Break(?)</td><td colspan="2">Break(?)</td></tr>
<tr><td>Kansas City</td><td>Francis</td><td colspan="2">Hoxbar</td></tr>
<tr><td>Marmaton</td><td>Wetumka-Seminole</td><td>Deese</td><td rowspan="2">Glenn</td></tr>
<tr><td>Cherokee</td><td>Thurman-Calvin
Savanna-Boggy</td><td>Cup Coral</td></tr>
<tr><td>Winslow</td><td>McAlester Hartshorne</td><td colspan="2">(?)</td></tr>
<tr><td>(?)</td><td>Atoka</td><td colspan="2">(?)</td></tr>
<tr><td>Morrow</td><td>Wapanucka
Upper Caney</td><td colspan="2">Otterville
Springer</td></tr>
<tr><td>Mississippian</td><td></td><td>Lower Caney
Sycamore</td><td colspan="2">Caney
Sycamore</td></tr>
</table>

Pontotoc Terrane.—The Pontotoc series was first named and described by Morgan.[1] He applied the name to a series of conglomeratic rocks containing a high percentage of feldspar (in places as much as 50 per cent) which crop out in the western

[1] MORGAN, G. D., Arkose of the northern Arbuckle area, *Okla. Geol. Surv. Circ.* 2, and *Bur. Geol.* 2.

part of the Stonewall quadrangle. This quadrangle embraces parts of Pontotoc, Pottawatomie, Seminole, Cole, Johnson, Murray, and Garvin counties. One of his main conclusions was that the arkosic sediments are of late Pennsylvanian age and that their first appearance marks the time when the Arbuckles were worn down to expose the central granitic core to furnish the feldspar in them. Rocks which are similar to the typical Pontotoc strata have been recognized in the counties immediately west of the area of outcrop. In Garvin and Stephens counties the correlation is based on the fact that between the base of the red shales and the Glenn formation there appear coarse sands and conglomerates with thin blue shales interbedded. In Stephens County, Gouin reports such conglomerates from one well, which are made up of fragments of limestone and chert with coarse sand filling the interstices. This zone is 600 feet thick. In Garvin County, the Pontotoc strata consist of conglomerates of chert, limestone, crystalline quartz, and pink feldspar. In Beckham County, the Pontotoc is represented by granitic detritus called granite wash by the drillers and interbedded shales and dolomites. The shales are brown, blue, and black. Both the shales and the dolomites become rapidly thicker away from the ridge of the buried mountain. The thickness of this peculiar rock is variable as would be expected. Gouin, in his report on Beckham County, mentions two wells, one of which had 276 feet and the other 1,565 feet. Greene in his article on the subsurface stratigraphy of western Oklahoma states that the arkosic beds on the flanks of the Wichita-Amarillo Mountain axis occupy a slightly higher position in the geologic column than those along the north side of the Arbuckle Mountains. This statement is based on the fact that the top of the arkosic beds correlates with younger beds more accurately than does the top of the Pontotoc beds in the type region.

Pre-Pennsylvanian Strata.—The rocks of systems older than the Pennsylvanian are of great importance in the oil fields of this province because they often contain the oil reservoirs. They crop out in the Arbuckle Mountains and have been described by Taff. The section is reproduced in Fig. 122. It shows the Mississippian to consist of 1,500 feet of shale and about 160 feet of limestone below. The shale is called the "Caney shale" and is mostly blue above and black toward the base. The

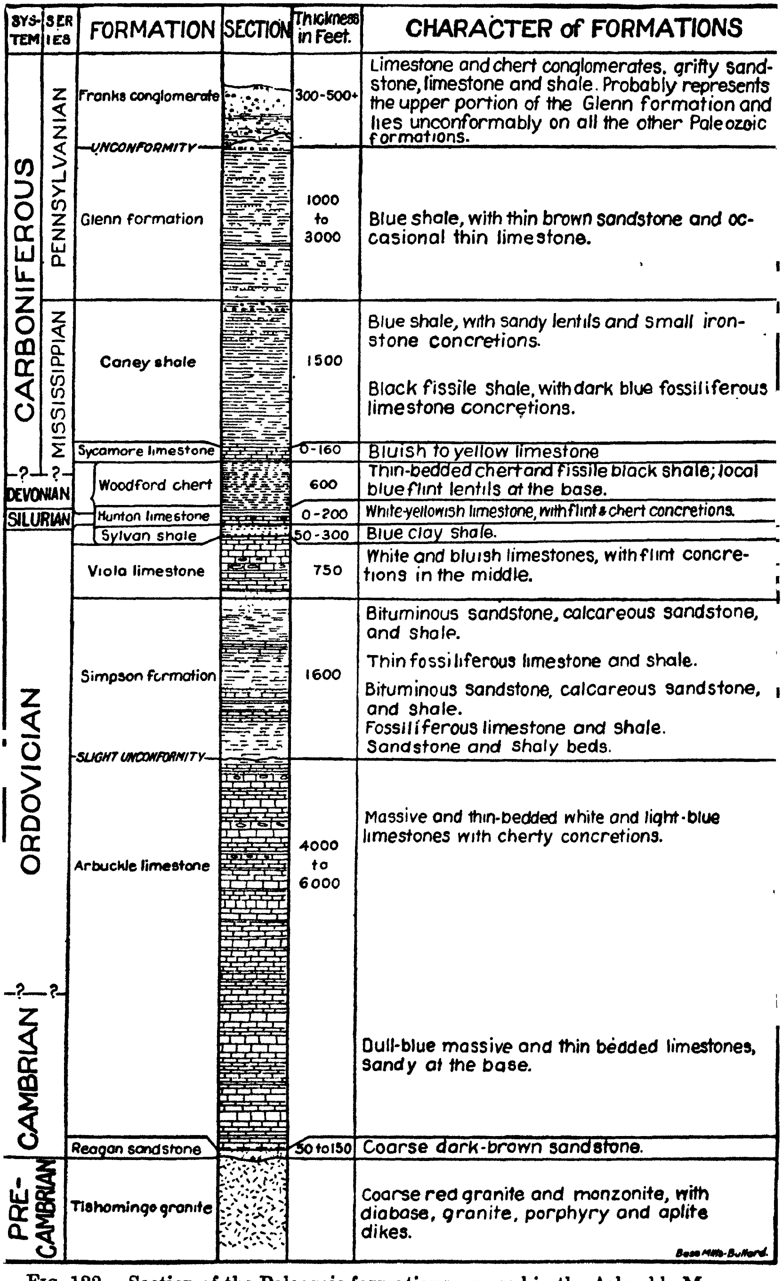

FIG. 122.—Section of the Paleozoic formations exposed in the Arbuckle Mountains. (*After Taff, U. S. Geol. Survey, Folio 98.*)

Sycamore limestone is a bluish to yellow limestone which varies greatly in thickness, due to an unconformity at the top of the Mississippian. It has been described very thoroughly by Cooper.[1] He states that the lithologic character of the Sycamore is so distinctive that it need never be confused with limestones above or below it in the section. Regarding the age of the limestone, he states that it appears to be of St. Louis age although the evidence is inconclusive at present.

The *Woodford* chert consists of black shale with thin beds of harder rock which seems to be limestone in some places and chert in others. In most cases the so-called "chert" is a siliceous limestone. This formation is thought to be the equivalent of the Chattanooga of northern Oklahoma. Below the Woodford lies the *Hunton* formation, which was described very fully in the last chapter. Similarly, the Ordovician formations were also described very fully on pages 243 to 252.

Producing Horizons.—The horizons which produce the oil and gas in the Ouachita-Amarillo Mountain province differ in one respect very noticeably from those which we have had occasion to discuss in other provinces. They are much more lenticular and limited in areal distribution than the others. Oil sands are usually lenticular, but some of them are very large lenses with an areal distribution of thousands of square miles. This statement applies to the limestone horizons particularly and to a few sandstone horizons. In the Ouachita-Amarillo province there are no sands of this kind and it is doubtful whether any of them, except the Ordovician horizons, extend over more than 20 square miles as continuous sheets. We shall therefore be unable to make a table of producing horizons for this province.

In a general way, the production in the province may be said to come entirely from the strata of Ordovician, Pennsylvanian, or Permian ages. The Pennsylvanian horizons are most important and greatly exceed the others from the standpoint of total production. In the Pennsylvanian strata the sandstones in the Glenn formation take precedence over all others, both in number and in productivity. In some areas, the Permian sandstones are very productive and in a few pools the Ordovician rocks have yielded much oil. The Pontotoc series is important locally and may be included among the important formations, if it develops that some of the production in the Panhandle district,

[1] Cooper (see Bibliography).

which is thought to be from Pennsylvanian strata, really comes from the Pontotoc horizon.

Beginning with the youngest strata, it is found that oil occurs in sandstones of Permian age in the Cement, Chickasha, and Carter-Knox pools of Caddo and Grady counties, in the Lawton pool of Comanche County, in the Doyle, Velma, and Milroy pools of Stephens County, and in the Robberson pool of Garvin County. In the Permian limestone, it is found that the Panhandle production heads the list. Great quantities of gas and considerable oil are produced from the *Big Lime* in that part of the province. The gas is found chiefly near the top of the lime and the oil somewhat lower stratigraphically. In the absence of fossils it is difficult to determine the age of the *Big Lime*, but most geologists now seem to agree that it is equivalent to lower Enid in age or to the Wichita of the Texas section. Its thickness of 800 feet and the finding of a few fossil fragments at one point, however, indicate that the lower portion is Pennsylvanian in age (probably Cisco according to the Texas nomenclature or Pontotoc according to the Oklahoma nomenclature). The Panhandle district is discussed in detail on page 323.

In the Pennsylvanian rocks, oil and gas are found in two formations, the Glenn and the Pontotoc. Both of these formations are locally very thick and have been subdivided into members as indicated in preceding pages. It is not possible to locate the oil horizons in any particular member of the formation and indeed it is difficult to decide whether the oil horizon is Pennsylvanian or not in many places. In the Pontotoc formation, oil and gas, or both, have been found in the Sayre field of Beckham County; in the Chickasha field of Grady County; in the Empire, Comanche, and Cruce pools of Stephens County; in the Lawton-Hanbury pool of eastern Comanche County; in the Robberson pool of Garvin County, and in a few other smaller pools. The Glenn formation has the most sands, and the most productive sands in it. These produce in the Empire pool of Stephens County where eight sands have been found in the Glenn at depths ranging from 1,700 to 2,600 feet. The highest is the Surber sand and the lowest so far found, the Maloney sand. The Surber and the Blaydes sands (found at 2,200 feet) are the most important. In the West Duncan pool, nearby, practically the same sands are found productive. In the North Duncan pool four sands in the Glenn produce. The

most important one there is the Thomas sand. In the Comanche pool of the same county the Wilson sand at the top of the Glenn, and a sand 400 feet lower (at 1,800 feet) are the two Glenn sands which produce important quantities of oil. In the Loco pool, also of Stephens County, two sands at 700 and 850 feet depth produce from the Glenn formation. In the Carter County pools, the Healdton, Graham, Hewitt, and Crinerville pools, the Glenn formation plays the important rôle. At Healdton there is a zone of lenticular sands called the "Healdton zone" which has produced an enormous amount of oil. Some sands are also found below this zone which belong to the same formation. At Graham, nine distinct sands or sand zones have been differentiated, all of them in the Glenn formation. This is a unique field in many ways and will be described more fully in succeeding pages.

The Ordovician rocks which crop out in the Arbuckle Mountains also appear under many of the pools farther west. They seem to have been faulted by powerful overthrust movements in late Ordovician time throughout the whole distance from central Arkansas to the Amarillo Mountain area in a direction from south toward the north, or from southwest toward the northeast. Subsequent erosion and cross-faulting have produced a series of old hilly tracts of resistant Ordovician strata over which later rocks, especially Pennsylvanian and Permian, were laid down. Indeed, we may say that nowhere have rocks, other than Pennsylvanian or Permian in age, been found above the Ordovician in the province west of the Arbuckles. In Carter County, three pools have found the Ordovician rocks and have obtained some production from them. They are the Crinerville, Healdton, and Hewitt fields. The only other field in which production was found in Ordovician rocks is the Robberson field in Garvin County. In many of the pools, during deep drilling, the same rocks were encountered but there was no production in them. The Arbuckle limestone was found in the North Duncan, West Duncan, Empire, and Comanche pools all of which lie on the trend (or closely parallel to the trend) of the Wichita Mountain axis in Stephens County. The Arbuckle limestone was also found in the Loco pool of the same county. In the Woolsey district, T. 2 S., R. 6 W. of Stephens County, the Simpson formation and the Viola limestone were found.

The following table of fields and producing horizons will give the reader an idea of the complexity of conditions in the Ouachita-Amarillo province.

PRODUCING HORIZONS IN THE OUACHITA-AMARILLO PROVINCE

Field	Producing horizons	Depth, feet	Age	Remarks
Texas Panhandle	Big lime		Wichita and Cisco (?)	Gas and some oil in porous streaks in lower 200 feet of Big Lime
	Granite wash			Disintegrated granite etc. fills embayments in mountains. Oil mainly in Carson County
Oklahoma Beckham County Sayre field	Dolomite		Pontotoc or Cisco	Oil at base of 60 foot dolomitic zone
Caddo County Cement field	Various sands	2,000 to 2,400	Permian basal	
Grady County Chickasha	Nichlos sand Ramsay	1,350 2,050 to 2,500	Permian Permian	Near base of Permian
Carter-Knox	Sands	1,600 to 2,000	Permian	
Comanche County Lawton	3 sands	400, 800, and 200	Pontotoc and Permian (?)	Hanbury extension has lower sands than these
Stephens County Empire	Gas sand	1,000	Permian	
	Miller sand Nigh sand	1,500 1,600	Pontotoc	
	*Surber sand Cantrell sand Shelton sand Smith sand Brown sand *Blaydes sand Kagny sand Maloney sand	1,700 1,800 1,900 2,000 2,100 2,200 2,300 2,600	Glenn	Top of Glenn form All Glenn sands are medium fine grained, soft, subangular, unconsolidated and surprisingly uniform throughout the pool. Arbuckle at 3,367 feet
West Duncan	Same sands approximately as in Empire pool			Arbuckle at 3,017 feet
North Duncan	Sand Thomas sand Sand Sand	1,800 2,000 2,100 2,300	Glenn	Top of Glenn at 1,600 feet Arbuckle limestone found at 2,880 feet
Comanche	Sand	800	Pontotoc	
	Wilson sand Sand	1,400 1,800	Glenn	Top of Glenn at 1,400 feet Top of Arbuckle at 3,410 feet
Loco	Loco sand Sand	700 850	Glenn	Other sands at 950, 1,000, and 1,500 feet not productive
Cruce	Sand	850	Pontotoc	Caney shale from 1,900 to 2,750 feet
Doyle	3 sands	950 to 1,250	Permian	Below 1,250 brown shales to 2,500 feet
Velma	3 sands	350 to 900	Permian	Ordovician at 1,745 feet
Milroy	3 shallow sands in		Permian	

PRODUCING HORIZONS IN THE OUACHITA-AMARILLO PROVINCE (*Continued*)

Field	Producing horizons	Depth, feet	Age	Remarks
Garvin County Robberson	Mauldin sands	1,200 to 1,600	Permian	Very lenticular sands
	Newberry sands	1,375 to 1,877	Pontotoc	Conglomerates
	Ordovician lime		Viola	
	Ordovician sand		Simpson	
Carter County Healdton	Healdton zone		Glenn	2 to 5 sands near top of Glenn
	Ordovician		Simpson	
Graham	9 sands		Glenn	See page 315 for details
Hewitt	7 sands		Glenn	Lenses in 700-foot zone
Crinerville	5 sands		Glenn	Pinching sands in Deese member
	Ordovician lime		Arbuckle, Simpson and Viola	
North-central Texas Wichita County Electra field	Shallow sands		Wichita	In this field there are 8 sands from 350 to 2,050 feet. All very patchy lenses
	Deeper sands in		Cisco	
	Deepest sands in		Marble Falls	
Burkburnett	Shallow sands		Wichita	In the Burkburnett field and extensions there are 7 sands from 400 1,800 feet
	Deeper sands in		Cisco	
			Marble Falls	
Clay County Petrolia field	Shallow sands in		Wichita	In this field there are 6 oil sands and 8 gas sands from 150 to 1,900 feet in depth
	Deeper sands in		Cisco	
	Deepest sands in		Mississippian	

Relation of Production to Structure.—In the Ouachita-Amarillo province the relation of production to structure is very close in most cases. The surface structure cannot always be worked out satisfactorily because of the lack of exposures or reliable key beds. In many fields, the sands are so patchy and lenticular that they do not tell much about the structure; still there are some sands in most of the pools which are sufficiently uniform and extensive to make contouring possible. In such cases pronounced domal or anticlinal structure is usually discovered.

An examination of Fig. 119, p. 290, will show a great many structural trends along which such domes and anticlines occur. Besides the major features, such as the Anadarko basin, Red River syncline, Red River anticline, Hunton arch, the Wichita and Arbuckle Mountains, a great many of the minor structures have received names.

Bearing in mind the prevailing trend of these structures as indicated on Tomlinson's map, and the geological history of the region as sketched at the beginning of this chapter, the conclusion is drawn that all of the oil pools in the province have had a common tectonic origin. The initial event which accounts for them was the folding (probably mild) and faulting which took place at the close of the Ordovician period. This produced long, narrow, structural elements trending mostly northwest and southeast. Some of these were continuous for long distances, but most of them were short and grouped *en echelon* in rough parallelism. In the eastern half of the province, from Carter County, east, erosion truncated the topographic hills formed in this manner throughout brief intervals of time only, for Silurian, Devonian, Mississippian, and Pennsylvanian rocks were laid down in considerable thickness over them. These strata were later subjected to renewed diastrophism along the old lines of weakness. At this time incompetent folds were formed, chiefly by vertical movements in the fault zones of the older Paleozoics. The most pronounced movements appear to have taken place during the middle of the Pennsylvanian period, for the Pontotoc series lies unconformably upon the Glenn series, indicating a break between middle Pennsylvanian and late Pennsylvanian times. The character of the Pontotoc, (being a coarse conglomerate of arkosic material and limestone and chert fragments) also suggests rapid erosion of a newly uplifted area.

In the western part of the province, from Carter County west, it is found that erosion was long continued after the late Ordovician movements, for the next period of sedimentation did not start until lower Pennsylvanian time and in many places not until upper Pennsylvanian or even Permian time. Most of the pools in Stephens County show a considerable thickness of lower Pennsylvanian (Glenn) sediments. Such pools were arched up after the middle of the Pennsylvanian period to produce incompetent folds similar to those formed in the eastern portion of the province. Spasmodic movements of similar nature occurred again at the close of the Pennsylvanian and during, or at the close of the Permian period, for it is found that certain of the pools have the surface rocks flexed as well as the older Pennsylvanian rocks. The most striking example of this is the Cruce pool in northeastern Stephens County, in which the Duncan sandstone reveals some sharp folding and steep dips. Steep dips in the Permian

are also reported from the western part of Oklahoma along the southern edge of the Anadarko basin.

The series of geologic events outlined above lead to the conclusion that we can expect to find very sharp folds (in which the rocks are nearly standing on edge) in the Ordovician strata beneath the present cover of younger rocks. Also we may expect to find moderately folded Pennsylvanian strata above such steeply folded older Paleozoics. One exception to this is the Graham pool in which the Pennsylvanian sands dip as high as 30 degrees on the flanks of the dome. In the Hewitt field the dip is also quite steep, in the Glenn rocks. Finally, we may look for very slight folding or none at all in the Permian rocks, as these were laid down in thin sheets over older hills and accumulated to greater thickness away from the hills. For example, in the Healdton field, the Permian strata are only 300 feet thick, whereas at a point but 3 miles from the axis of the fold, the thickness amounts to 2,400 feet. Cases like this, involving only Permian strata, or Permian and Pennsylvanian strata, are numerous in Carter, Stephens, and Comanche counties.

Production in the Ouachita-Amarillo Mountain petroliferous province is therefore distinctly related to the structure. It occurs only over buried hills or anticlines where the older rocks have been greatly disturbed and where as a rule the Pennsylvanian strata are noticeably arched. Two zones of Ordovician disturbance cross in this province; the Bend-Ozark and the Ouachita-Amarillo zones. These two zones intersect broadly between the Arbuckle and the Wichita Mountains, especially in Stephens and portions of adjacent counties. We can therefore postulate oil migration from the east and the west toward the Bend-Ozark zone as well as migration from the south and the north toward the Ouachita-Amarillo zone. This is probably the reason why pools have been found more numerous and oil production more prolific in the Stephens County area in Oklahoma and the Clay County area in north Texas. In order to bring out more clearly the relation of production to structure a number of typical fields will be described in detail.

ARBUCKLE-WICHITA DISTRICT

The Robberson Field.—A typical field of this province is the Robberson oil field of Garvin County. It is located in the southwest corner of the county on the trend of the Arbuckle

Mountains as shown in Fig. 123 taken from an article by Roth. Although the region in which this pool is located was looked upon with favor for many years on account of the asphalt deposits

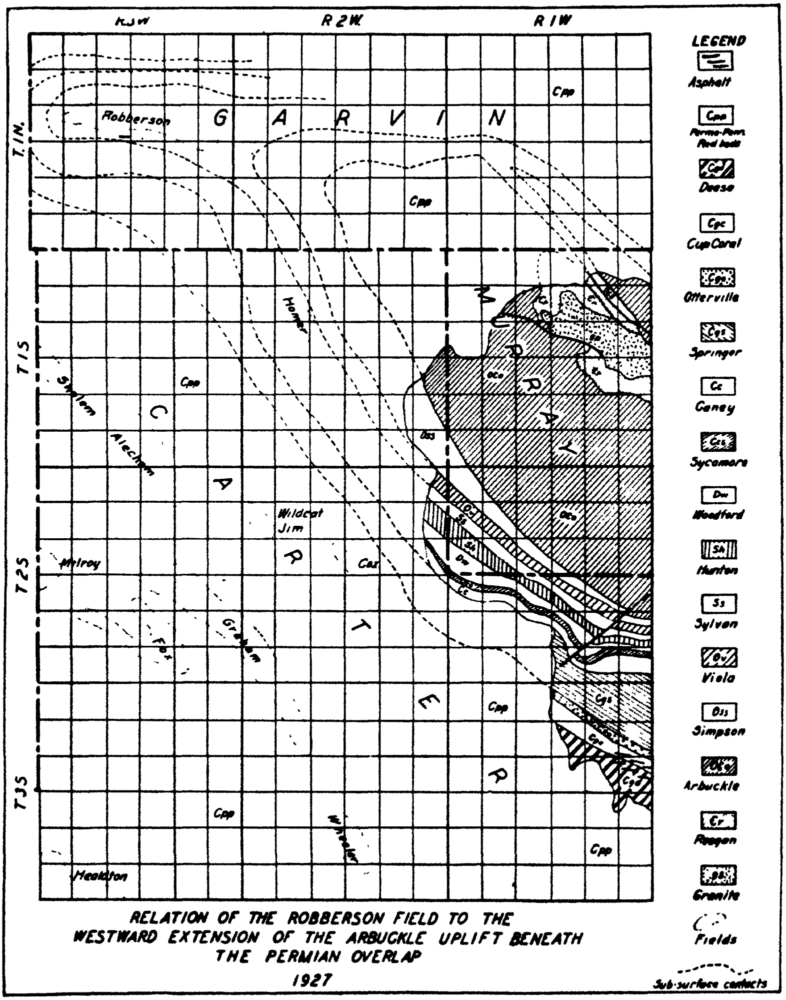

FIG. 123.—Westward extension of the Arbuckle Mountains. (*After Roth, Okla. Geol. Survey Bull.* 40 K.)

noted by Eldridge, in 1901, it was not opened up until 1920 when the Magnolia Oil Company drilled a gas well in Sec. 16. Oil was found a year later by the same company in Sec. 14. The first well yielded 200 barrels per day and greatly stimulated activity.

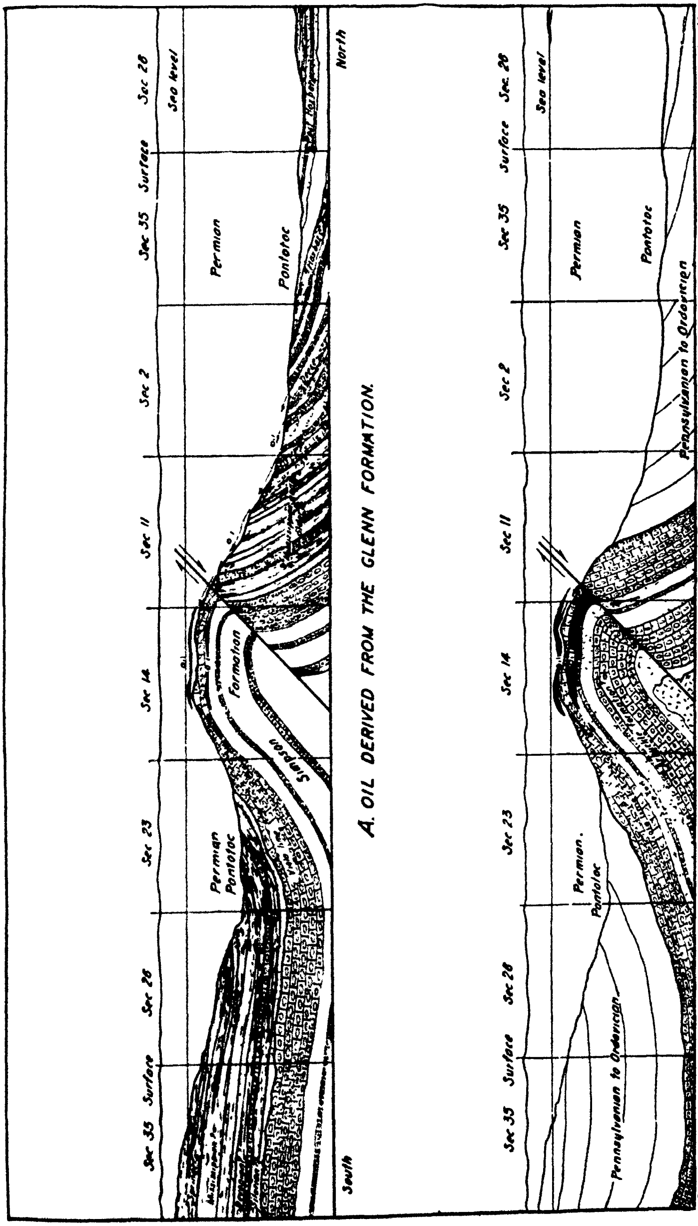

FIG. 124.—Generalized cross-sections of the Robberson field. (*After Roth, Okla. Geol. Survey Bull.* 40 K, p. 48, Fig. 7.)

In August, 1922, the first gusher was found producing 1,000 barrels per day. Later, some wells produced as high as 8,000 barrels per day.

The surface rocks consist of alternating shales and sandstones with some thin limestones, all of Permian age. These rocks having a thickness of about 1,200 feet are called the Garvin beds, locally. Below the surface much coarse material is found, gravel beds and arkosic beds being common. At the base of the Garvin beds is a persistent limestone which may be used as a key bed for subsurface contouring. Below this limestone there are 400 feet of Permian strata, consisting of red, brown, and blue shales with thin sand lenses. These sand lenses contain considerable gas. The Garvin and Mauldin beds rest upon the Ordovician strata with an unconformable contact (see Fig. 124). In the old ravines and gullies of the buried hills, as well as on the flanks of the hills, other extremely lenticular sediments were deposited which contain coarse detrital materials and some sands. They are probably to be correlated with the Pontotoc terrane and represent old soils and talus slope materials which were reworked in late Pennsylvanian time by encroaching sea water.

The relation of the young Paleozoic rocks to the older Ordovician strata is shown in the two cross-sections presented in Fig. 124. It will be noted that the Ordovician is represented by the Viola limestone, the Simpson formation, and the Arbuckle limestone. The Viola limestone has been eroded at the crest of the buried hill so that it varies considerably in thickness. The Simpson formation is within reach of the drill at the crest of the structure and contains oil in a sandstone which may be the Wilcox sand.

Figure 124 also shows a reverse fault or thrust fault which gives us a clue to the tectonics of this area as well as similar areas in the province. Naturally, such faults are very difficult to work out from the well records and must be considered somewhat hypothetical. Nevertheless, the cross-sections probably represent the conditions as they are with the possible exception of the Mississippian and older post-Viola strata shown. The structure on the top of the Viola limestone is shown in Fig. 125. It will be noted that the surface of the Viola is very irregular due to erosion and also that the north flank of the structure is much steeper than the south flank probably due to the effects of the faulting on that side. The dip on the south flank amounts

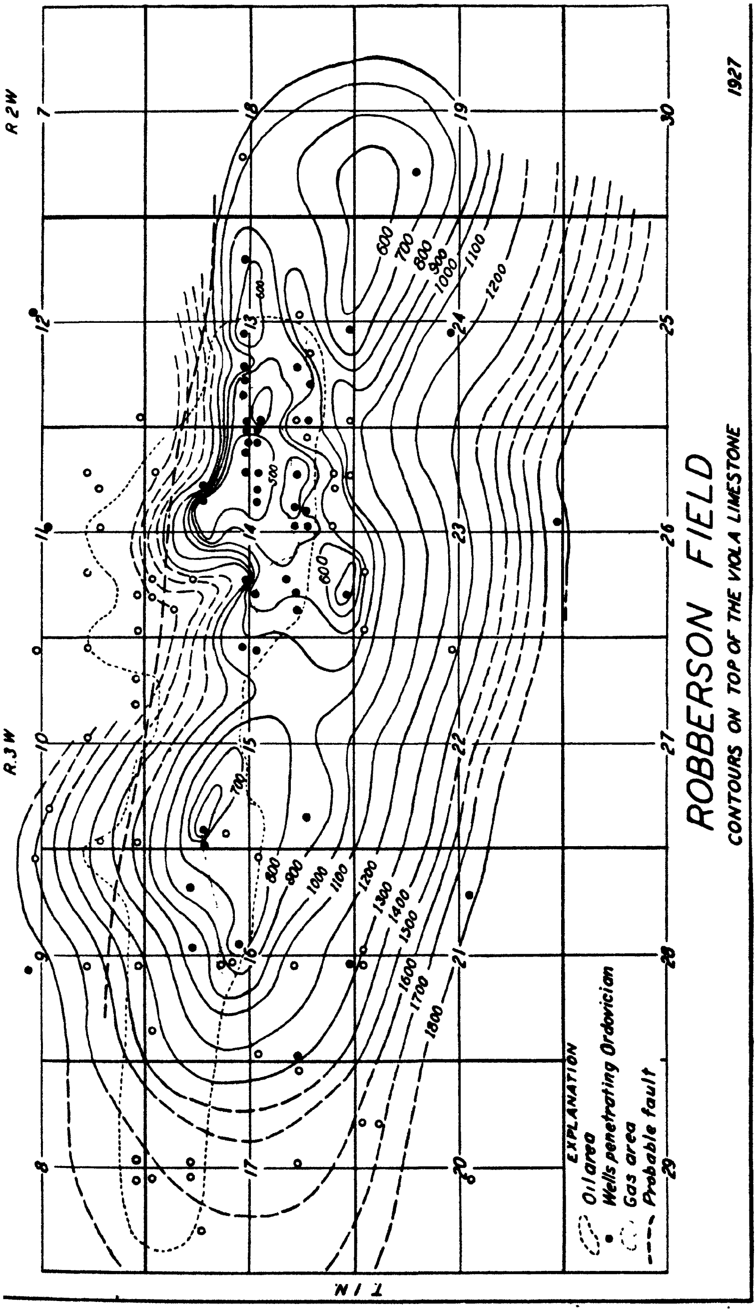

Fig. 125.—Contour map of the Robberson field. (*After Roth, Okla. Geol. Survey Bull.* 40 K, p. 40, Fig. 5.)

to over 1,000 feet in a mile, but on the north flank it is twice as steep.

Gas is produced in the Robberson pool at various depths in the Permian from 1,200 to 1,600 feet. The reservoir sands are very patchy lenses and cannot be correlated from well to well as a rule. In the Pontotoc series the oil sands are found; they also have very patchy lenses. Examination of samples from drill cuttings shows that the producing sands consist of loosely consolidated fragments of limestone, chert, quartz, and feldspar. Some of these fragments are rounded, but most of them are quite angular. Apparently, this material was derived from the nearby Arbuckle

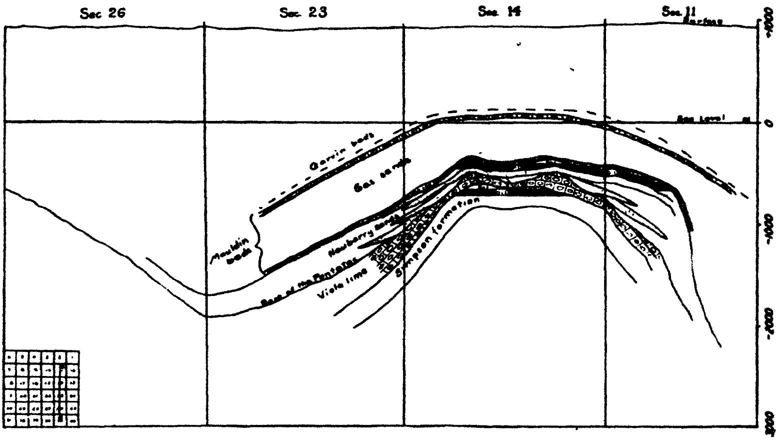

FIG. 126.—Cross-section of the Robberson field. (*After Roth, Okla. Geol. Survey Bull.* 40 K, p. 37, Fig. 4.)

Mountain area and deposited after being transported for short distances only. The largest production of oil occurs in the Ordovician strata, both the Viola and the Simpson being found productive. Figure 126 shows the position of the pay zones and the relation to structure. Very evidently the oil and gas have taken positions according to the anticlinal theory and on the flanks of the structure only water is to be expected. Very little water has been found, however, except in the Ordovician. The chemical analysis of the oil reveals the fact that both the Ordovician oil and the oil in the Pontotoc sands are the same in character; consequently, it is assumed that the source is the same. Roth inclines to the belief that the oil originated in the Ordovician limestones and migrated into the Simpson sands as well as to the

higher sands after uplift took place. He also states that the Glenn may have been the original source of the oil or that both sources are possible. The oil produced at Robberson varies from 25 to 33° in gravity, the average being 28°. The lightest oil is found in the Simpson sands and the oil becomes progressively heavier up into the Permian. Up to the middle of 1927, a total of 342 wells had been drilled, of which number

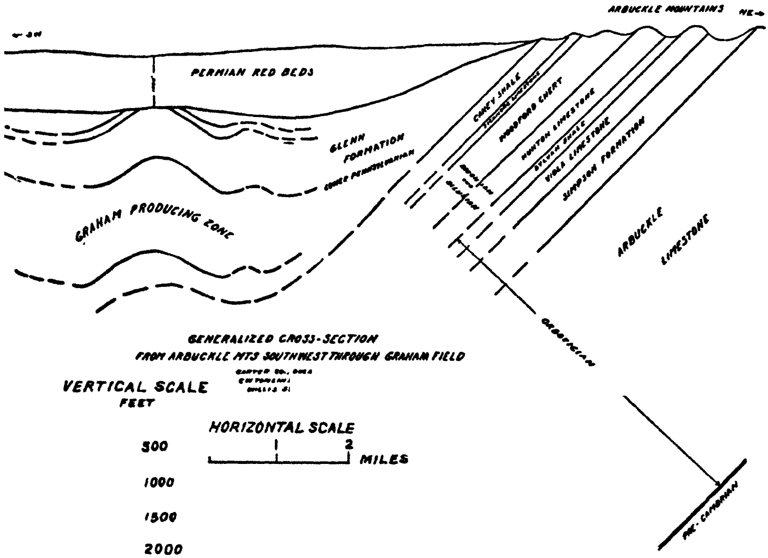

FIG. 127.—Generalized cross-section from Arbuckle Mountains southwest through Graham field. (*After Tomlinson and Storm, Bull.* A.A.P.G., **8**, 600.

221 produced both oil and gas and 52 only gas. The rock pressure in the gas wells varied from 275 to 600 pounds. The gas wells have a fairly long life, the decline curves for the oil horizons showing a strong contrast. The Newberry sands (Pontotoc) show a rapid but regular decline and very little flattening until the wells are a year old. The Ordovician strata produce great quantities of oil at first, but decline rapidly, the curve flattening at the end of 7 months. Some of the wells from the older rocks showed a very rapid decline as, for example, one of the Humble Oil Company wells came in for 8,000 barrels and in 1 month was

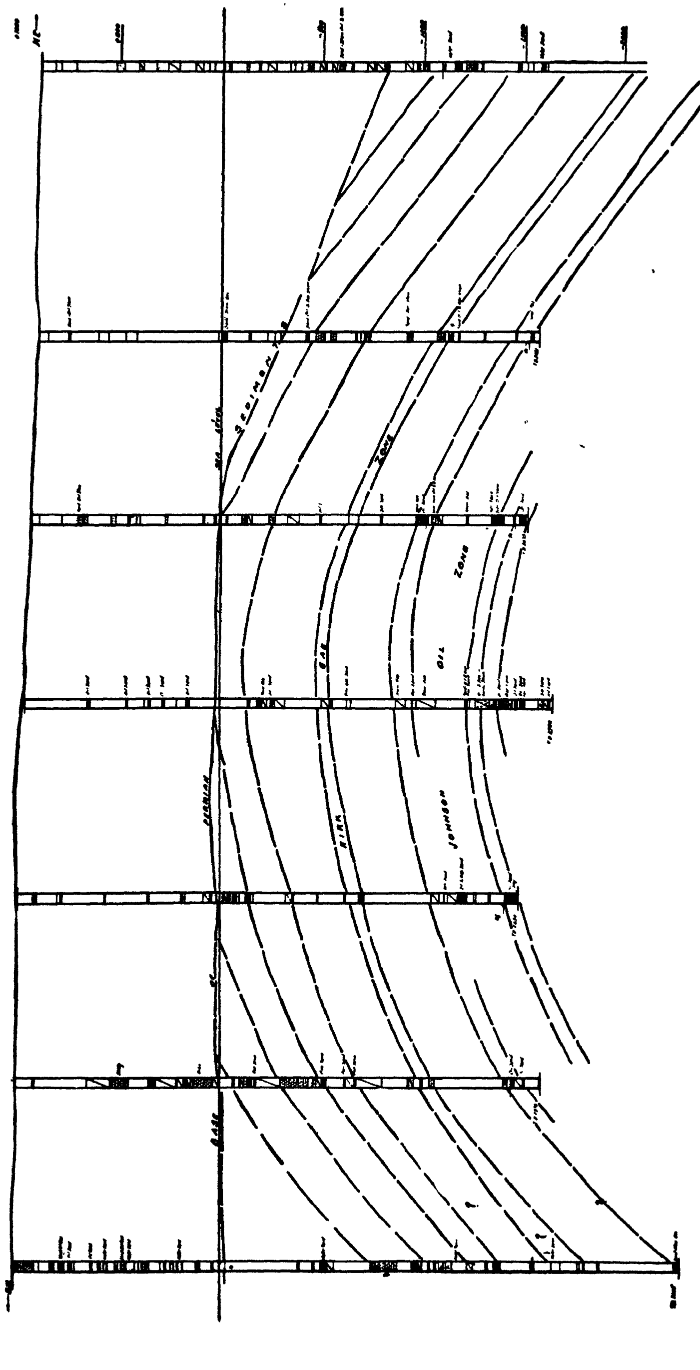

FIG. 128.—Profile cross-section, Graham field. (*After Tomlinson and Storm, Bull. A.A.P.G.*, **8**, 597, Fig. 2.)

pumping only 50 barrels. Up to the end of 1929, the total production of the field amounted to a little over 6,000,000 barrels, which figures out to a per acre production of only 1,680 barrels.

The Graham Field.—One of the most interesting fields in this province is the Graham field. It is typical in many respects of all the fields in this province, but also shows a number of unique features which will bear emphasis. The Graham field is located in the northwestern part of Carter County, Oklahoma, and covers an area 4 miles long and ½ to ⅞ mile wide. This field, like many others, was located on the strength of asphalt exudations, since the surface rocks of Permian age do not reflect the structure beneath. The first well was drilled in 1917 and a very heavy oil was found in the red beds at the shallow depth of 250 feet. Other wells were drilled at intervals during the next 6 years, but none of them were very large. In 1923, the first large well was drilled, and it provided the necessary stimulus to more rapid development.

Figure 127 shows the tectonic setting of the Graham pool. It lies south of the Arbuckle Mountains and apparently on a very deeply buried parallel structure in the Ordovician rocks. The structure of the rocks is not revealed at the surface and the Permian rocks probably lie horizontally or dip, at a gentle angle, northeastward. The Permian rocks are from 800 to 1,200 feet thick. With a strong contrast in dip, the underlying Pennsylvanian strata dip both north and south at very strong angles. At a few points the dip amounts to 30 degrees, which is very exceptional in this province, the nearest rival being the Hewitt field with dips as high as 15 degrees. Figure 128 shows some of these features as well as the truncated top of the anticline in the Pennsylvanian rocks. On the southwest flank of the anticline the dips range from 8 to 25 degrees with an average of 22 degrees; on the northeast flank they range from 16 to 30 degrees with an average of 28 degrees. At least one of the producing sands contains oil down the flank of the fold to a depth of 1,000 feet below the crest.

The oil sands in the Graham field extend through a vertical range from 250 to at least 3,400 feet. The upper sands are in the Permian and Pontotoc (?), and are not commercially important, the oil in these sands being heavy and the yield small. Below 800 feet on the crest and about 1,200 feet on the flanks, the Pennsylvanian oil sands appear. They are unusually numerous,

no less than eight sands or sand zones having been discovered to date. The Kirk gas zone is the first of these which is commercially important. About 500 feet lower lies the Johnson-Atlantic sand zone. It averages 300 feet in thickness and may be a single sandstone or may be represented by a number of thinner sandstones separated by shales. About 50 feet from the top of this zone, the main gas-producing sand of the pool is encountered and is called the "Johnson sand." It is also one of the chief oil horizons. The oil production from the Johnson ranges from wells producing from 10 to 15 barrels up to wells having 1,000 barrels initial production. The gas production runs as high as 43,000,000 cubic feet per well. On account of the dip the depth at which this sand produces varies from 1,750 to 2,900 feet and it produces over a wider area than any other sand. The maximum thickness of the Johnson sand is 100 feet, but the average is much less and in some locations it is missing entirely. As a rule, it is separated from the Atlantic sand by a shale break. The Atlantic sand locally yields good wells, some having had 1,000 barrels initial production. Its rapid variation in lithologic character to shale and even limestone makes it undependable. The Ricketts sand found about 130 feet lower has yielded the largest wells found in the field, but it is extremely patchy and lenticular.

The Graham sand, lying 500 feet below the Johnson, was so named because it was the main reliance for production in the earlier developed central portion of the field, where it yielded more uniform and better production than higher sands. It varies in thickness from 10 to 125 feet and in the northwestern half of the field it changes to shale. The Bennett sand has produced some oil but is not an important horizon. The Sutherland sand lies about 250 feet below the Graham sands and has furnished some good wells, but its usually well-cemented character does not presage large production. Some wells have penetrated 400 feet of strata beneath the Sutherland and have found a sand which has been named the Smith sand. The depth to the Smith sand varies from 3,200 to 3,400 feet. It is from 10 to 40 feet thick and has not yielded any wells with more than 25 barrels initial production.

In other near-by fields (see Fig. 119, p. 290), such as the Hewitt, Healdton, and Brock fields, the Ordovician strata have been found at much shallower depths than the greatest depth pene-

trated in Graham. If these strata are within drilling depth, they may be found to yield commercial quantities of oil as they have in other areas.

The most interesting feature of the Graham field is the distribution within it of different grades of oil, ranging from a minimum of 27.5 to 43° Bé. Oil above 39° has been obtained only from the Sutherland and Smith sands and oil below 32° has been obtained only from the Johnson sand. The remarkable feature is that each of the sands shows a vertical gradation in gravity, which in some cases is quite marked. Within the Johnson sand, for instance, there is a range of gravity from 27.5 to 38° Bé. The lines on the map showing the areas which produce different gravity oil show a very close parallelism to the contour lines showing the structure. Tomlinson and Storm believe that this remarkable variation in gravity distribution is due to segregation of different qualities of oil in the same sand under the influence of gravitation. Gas bubbles rising to a higher position are believed to have a tendency to carry along the lighter constituents and leave behind the heavier constituents. Vertical differentiation has also been aided no doubt by the steep dips of the sand. The source of the oil appears to lie within the Glenn series, although the dark-colored Caney shale below may have contributed some or much of it. Since the deepest sands produce the lightest oil and there is a gradation in each sand, this presents a case of oil growing lighter with stratigraphic depth and heavier with structural depth.

An average ultimate yield of from 7,000 to 25,000 barrels per acre is expected from the field.

Production Statistics.—The oil pools of Stephens County have proved to be the most prolific in the Oklahoma portion of the Ouachita-Amarillo province. Gouin[1] has furnished a list of the fields showing the leases separately with the number of acres and wells as well as the yields per acre and production per well. The following figures are mostly taken from his report: In the Empire pool the production per acre amounts to over 9,000 barrels and the average production per well to nearly 48,000 barrels. On the Magnolia school-land lease, the production per well amounts to 90,000 barrels. The highest per acre production is shown by the Old Colony Kagay lease which shows over 24,000 barrels per acre. In the West Duncan pool per-acre yield runs

[1] Gouin (see Bibliography).

to about 7,000 barrels, and total production per well to 40,000 barrels. The North Duncan pool shows approximately the same figures, as does also the Comanche pool. All of these pools lie on the trend of the Wichita Mountain axis (see Fig. 119, p. 290). The average gravity of the oil in these three or four pools is about 39°. It is expected some or all of these pools will produce ultimately 50,000 barrels per well and 9,000 barrels per acre.

RED RIVER UPLIFT DISTRICT

The fields of north-central Texas are included in the Ouachita-Amarillo petroliferous province because of tectonic similarities. Most of the production in this part of Texas comes from Wichita County in which the famous Burkburnett pool with its extensions (the Northwest, Southeast, and the Townsite pools), the Clara, Hirshi, Electra, and K.M.A. pools are located. The Electra pool reaches over into Wilbarger County on the west. In the north-central part of Clay County lies the Petrolia pool, and near the Red River in the northern part of Montague County lies the Nocona pool.

The tectonic elements which seem to have controlled the accumulation of oil in these areas is the Red River uplift which according to Fuqua and Thompson is a chain of dissected Cambro-Ordovician limestone and granite hills. Hager described the Red River uplift or anticline on the basis of finding granite at a comparatively shallow depth in some wells near Petrolia and the finding of Ordovician rocks at depths around 3,500 feet in a number of localities in this part of Texas. The Bend arch which starts in the Llano-Burnet uplift near central Texas pitches north (see Fig. 134, p. 333) and can be detected in Young and Jack counties where it lies at a depth of 4,000 feet below sea level. Nothing is known of it in northern Young or Jack counties and we are equally in the dark about it in southern Archer and southern Clay counties. In northern Archer and central Clay counties the Ellenburger limestone, which is the same as the Arbuckle limestone in southern Oklahoma, appears to lie considerably higher than it does in southern Young and Jack counties. It has been found at depths of about 3,100 feet below sea level. This may indicate that the arch has a deep saddle on it in southern Archer County and adjacent territory or it may mean that we have entered the province of east and west faulting which is so characteristic of the Ouachita-Amarillo province. An over-

thrust anticline running nearly east and west through Wichita, Clay, and Montague counties which brings up the Ordovician and older granitic basement rocks is very logically postulated, as it would fit in with the typical orogeny of the Ouachita-Wichita-Amarillo Mountain tract nicely.

Stratigraphy.—The succession of rocks in north-central Texas has been described by Fuqua and Thompson. The surface rocks are of Permian age and belong to the Clear Fork and Wichita formations which correspond to the Enid formation in Oklahoma. In the Red River district of Texas, these strata are about 1,100 feet thick and consist of red shale and red sandstone. The sandstone beds are thin and occur at intervals of from 30 to 60 feet in the section. They are very lenticular and, therefore, any individual bed cannot be traced very far. The Wichita-Albany beds lose their red color toward the west.

Below the Wichita beds lie other red beds essentially similar to the Wichita strata. The upper 400 feet consist of red shales and thin sandstones but below that level limestones begin to come into the section. These rocks are the uppermost Pennsylvanian and have been correlated with the Cisco formation. Measured on the outcrop in Eastland, Stephens, and Young counties[1], the Cisco varies from 900 to 1,800 feet and consists of alternating beds of shale, sandstone, and limestone with several thin coal seams near the middle. Below the Cisco formation lies the Canyon formation, also of Pennsylvanian age. This formation is made up of shale and limestone, chiefly, with sandstone relatively scarce. In central Texas, four massive limestones have been differentiated by name in the Canyon formation and have been used for surface mapping. They are the Home Creek, Ranger, Adams Branch, and Palo Pinto limestones, named from top to bottom. They can be traced in well logs toward the producing areas of north-central Texas, but, before that district is reached, become very sandy and shaly and, therefore, lose their value as key horizons. It is likely that a portion of the Canyon is entirely missing in the pools of north-central Texas. The Strawn formation which normally lies below the Canyon formation in central Texas also appears to be missing entirely. This is the coal-bearing series of northern Texas and also contains many important oil and gas horizons in central Texas in Eastland, Stephens, Young, and Schackelford counties. In the type log

[1] Plummer and Moore (see Bibliography).

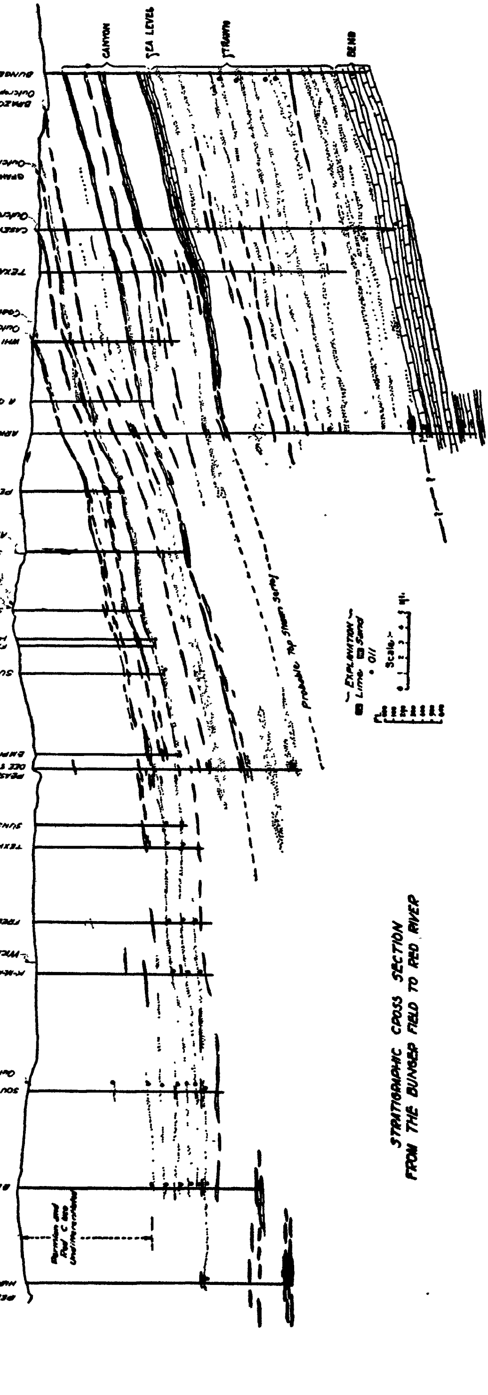

FIG. 129.—Stratigraphic cross-section from the Bunger field to Red River. (*After Hubbard and Thompson, Bull.* A.A.P.G., **10**, 480, Fig. 6.)

for the Electra district, there are some very massive limestones at a depth of 2,600 feet and above that level from 2,200 feet there is much limestone. This has been thought to be the Bend lime or Marble Falls limestone of lowest Pennsylvanian age. If the well-log correlations are traced north from the central Texas area, the finding of this limestone at the depth indicated would show that the Strawn had been entirely eliminated and most of the Canyon as well. Further deep drilling and careful study of well cuttings will be necessary before definite statements can be made on this important point. One deep well penetrated 400 feet of Arbuckle limestone below the Pennsylvanian rocks and entered granite at 2,900 feet.

Producing Horizons.—The producing horizons in north Texas are similar to those of the rest of the Ouachita-Amarillo province in their extreme lenticularity and patchy distribution. Oil and gas have been found at many different levels, but it is impossible to trace any one of them very far horizontally. Some of them have received names but most of them are known by depth only in the respective pools where they are found. In the table (p. 305), the producing horizons are listed. The shallow sands down to a depth of about 600 to 800 feet belong to the Wichita formation of Permian age. With the exception of the deepest producing horizons all the other sands appear to belong to the Cisco formation. Figure 129 shows the typical section of central Texas carried northward to show the correspondence with the Electra and southern Wichita County pools. Because of the similarity of the Wichita and the upper Cisco beds, they are not separated in the drawing.

Relation of Production to Structure.—It is very difficult to work out the structure of the surface because of the lack of reliable key beds. Similarly, it is difficult to work out structure on subsurface horizons because they are so patchy and uncertain. Some parts of the area, however, have been worked out and some details of the structure are available. Fuqua and Thompson[1] have given us the most recent information on these fields. According to their report the structure of the Wilbarger County pools is anticlinal. Figure 130 shows the structure of central Wilbarger County and indicates that the producing area (oblique lines) corresponds closely to the subsurface structure. The ultimate production is estimated at from 8,000 to 13,000 barrels per acre.

[1] See Bibliography. Also Kendrick and McLaughlin.

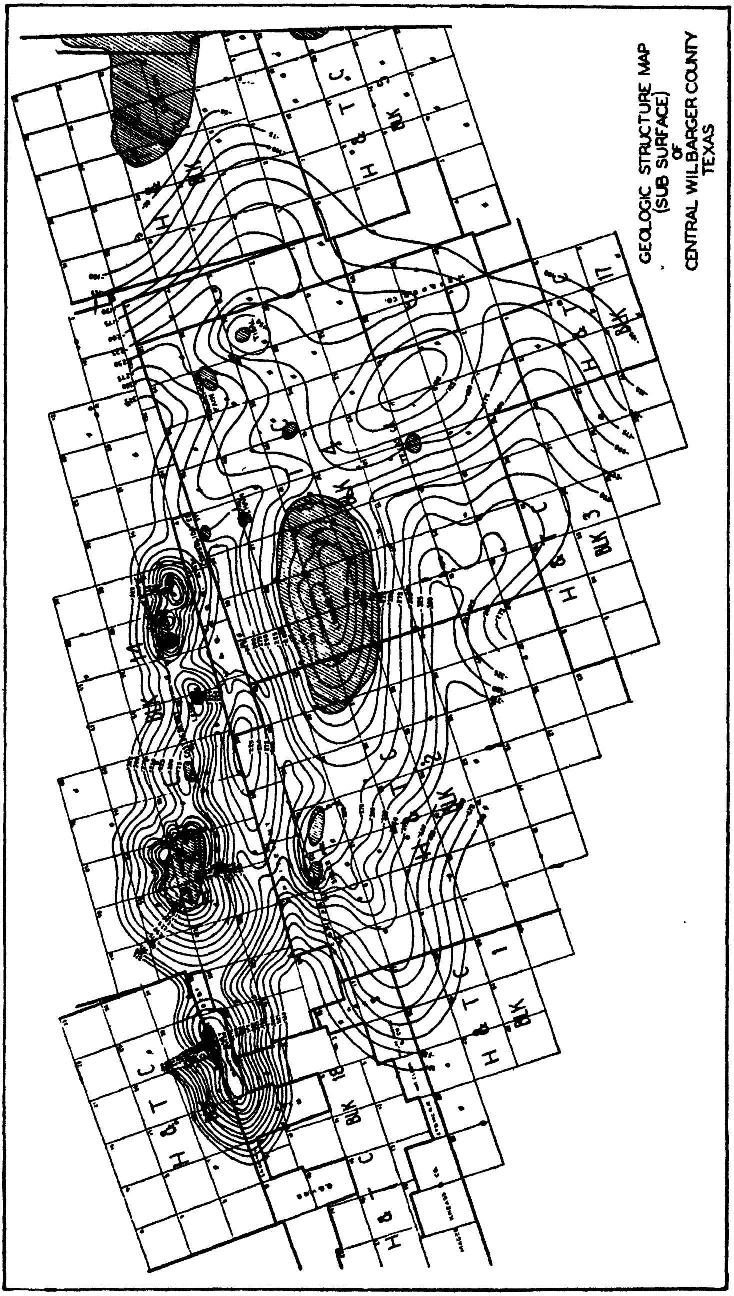

FIG. 130.—Geologic subsurface map of central Wilbarger County. (*After Fuqua and Thompson, A.A.P.G. Symp.*, 1.)

AMARILLO MOUNTAIN DISTRICT

The first well drilled for oil in the Panhandle of Texas was drilled upon the advice of Gould by the Amarillo Oil Company early in 1918. Gould had conducted surveys in that part of Texas for a number of years and was impressed by the structural conditions he found along the Canadian River. No interest was shown in the region because of the fact that the Permian beds were not expected to contain oil and the Pennsylvanian was thought to lie too deep. Besides that, much of the area was covered by tertiary rocks which concealed the structure of the Paleozoic strata. The first well encountered gas in December, 1918, in Potter County. Three years later the first oil was discovered in northern Carson County quite a distance from the first gas strike. Subsequent drilling has revealed one of the largest oil and gas pools of the world, as regards size, and probably the largest gas field of the world, as regards production. The area in which gas wells of a capacity of 10,000,000 or more cubic feet per day are found covers 1,483 square miles or 949,210 acres. This is divided by counties as follows: Hartley, 24.8 square miles; Moore, 447.1 square miles; Potter, 183 square miles; Hutchinson, 197 square miles; Carson, 295.5 square miles; Gray, 193 square miles; Wheeler, 138.5 square miles, and Collingsworth, 3.3 square miles. Figure 131 shows the area which contains the gas wells and also the area in which oil has been found. It will be noted that practically all the oil pools are small and located on the northern edge of the gas-bearing area. The largest oil pool is the Borger field in south-central Hutchinson County. Southwest of this is the Sanford oil pool and southeast in a string trending toward the southeast lie the McIlroy, Roxana, Noel-McConnell, Wilcox, Bowers, Gulf-Saunders in Carson and Gray counties, and the Shamrock pool in central Wheeler County.

Tectonic Elements.—The tectonic elements which control the occurrence of oil in this part of the Ouachita-Amarillo Petroliferous province were described rather fully in the first part of the chapter, therefore only a few details will be added. The chief tectonic element is a buried mountain ridge of granite which was formed probably in late Ordovician time. It was a land mass during the succeeding Silurian, Devonian, Mississippian, and part of the Pennsylvanian periods. Disintegration and partial decomposition of the granite hills caused great sheets of arkosic material to accumulate in the low places and around the

the Triassic, and below the Quartermaster the Cloud Chief red beds and Day Creek dolomite appear. Below the 800 feet of upper Permian, drilling has revealed 500 feet of red sandstones and clays, and below that another 500 feet of red beds in which gypsum and dolomite are conspicuous. These strata are succeeded by other red beds in which salt is present in considerable quantity; finally, down to a depth of about 2,000 feet more, red beds appear with some gypsum, anhydrite, and limestone. This brings us to the top of the most important zone of rocks called the "Big Lime" by the driller. In reality it is not a limestone but a mixture of limestone, anhydrite, and dolomite strata interbedded with light-blue or pale-green shales. The average thickness of the zone is 800 feet. It is thinner on the crest of the anticline and becomes thicker on both sides. At a distance from the granite ridge it changes horizontally to a thick blue shale terrane.

Below the Big-Lime zone, the drill encounters arkosic sand and conglomerate in variable thickness. Since it fills holes in the granite and extends out on the flanks it may be very thick. Farther away from the granite ridge it also changes horizontally to rocks of different lithology, chiefly limestone and shale. Figure 132 shows some of these features very well.

Producing Horizons.—The Big Lime is the main producing horizon in the Panhandle fields. The main gas-producing zone lies in the basal 200 feet of the lime in which it occurs at various levels, according to varying porosity conditions. An average thickness of the porous zone in any one well is about 35 feet. Gas seems to fill all the higher portions of the porous zones in the Big Lime and the oil is therefore only found on the flanks in that zone. Oil also occurs lower stratigraphically in the so-called "granite wash" (the arkosic sand, and gravel). This material consists of angular fragments of quartz and feldspar with very little cementing substance. At some points it extends as far as 4 or 5 miles away from the granite ridge, but usually is found close to it only. Oil is found above sea level or rather 20 feet above sea level, for below that level only water appears. This, of course, is merely a coincidence and has nothing to do with the water in the oceans at the present time.

The gravity of the oil found in the Panhandle is very similar throughout the district. It ranges from 34 to 37° Bé. and congeals at a temperature of 50° F. Inasmuch as the water table is

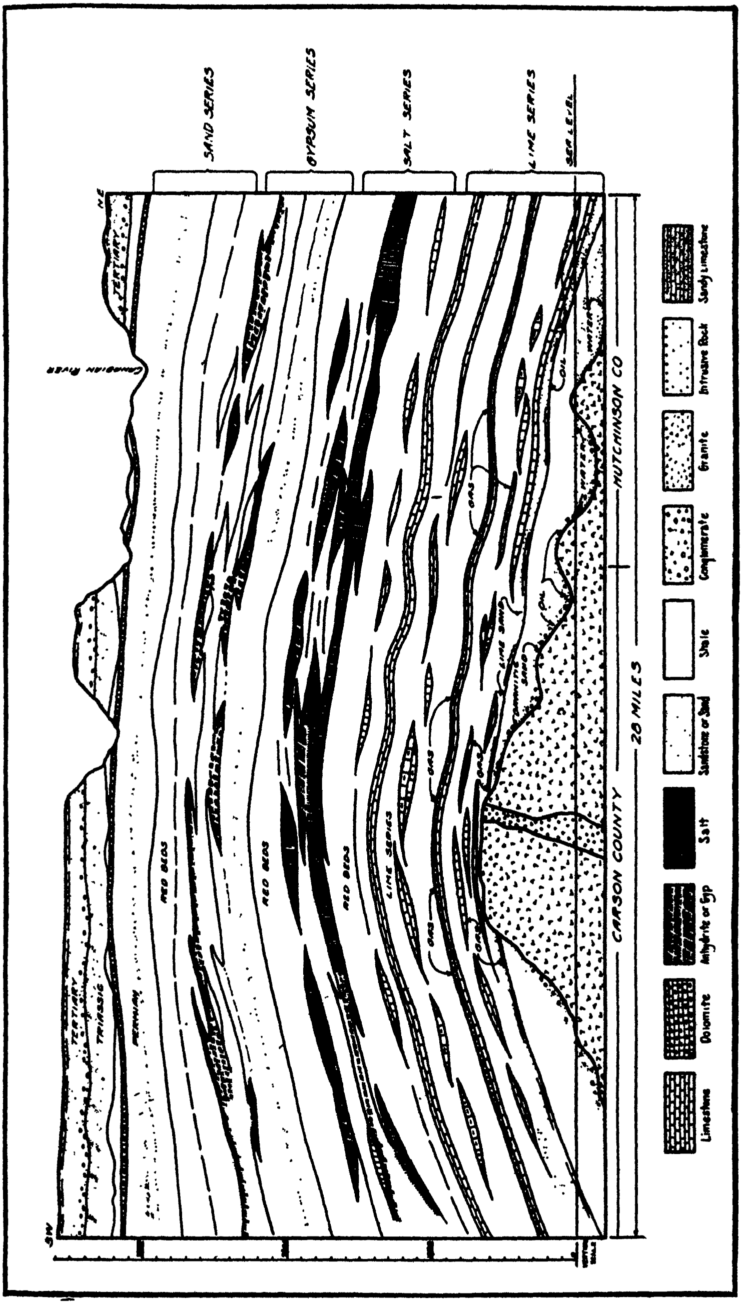

FIG. 132.—Ideal cross-section of the Panhandle anticline. (*After Bauer, Bull.* A.A.P.G., **10**, 737, Fig. 1.)

fixed nearly at 20 feet above sea level, it is believed that the pressure behind the oil is entirely due to the imprisoned gas. The fact that the oil congeals causes trouble in transportation and the high content of wax makes some trouble for the refiners. In 1929, the production of oil was approximately 86,000 barrels per day.

The gas reserves in this part of the world are enormous. Bauer[1] estimates the total recoverable gas present in the Panhandle fields, before drilling began, at 158,000,000,000 cubic feet, at 430 pounds pressure. Or stated in other words, if 500,000 cubic feet should be removed each day the supply would last for 24 years. If the recovery is higher than 50 per cent, which is the figure used in the calculations, then the total amount will be that much greater. The wells are all large and some of them are capable of producing in excess of 100,000,000 cubic feet per day. One of the perplexing features about the gas is the subnormal pressure of about 450 pounds per square inch. This pressure originally was the same all over the field and in all producing horizons. It is about half the hydrostatic head at sea level where the water table lies. Inasmuch as the strata finger out in all directions into shales and other impervious rocks, no artesian water has been added to the original connate water. Bauer explains the diminished pressure and receding water table as due to the change of gypsum to anhydrite of which there is a great deal in the stratigraphic section. At the beginning of 1928, the pressure had gone down considerably. In the Borger and Dixon Creek areas the pressure was as low as 120 pounds, in the Pampa pool down to 275 pounds, and in the Sanford pool down to 350 pounds. Inasmuch as the same pressure over the whole field at the beginning proved the intercommunication of all areas, this will result in gas moving from higher pressure areas to those of lower pressure and thus offset the decreased pressure at certain places. In time, of course, the pressure will tend to become equalized again.

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CHAPTER VII

THE BEND ARCH PROVINCE

South of the fields just described in the north-central portion of Texas, and separated from them by a fairly deep syncline or saddle, are the fields of central Texas. They lie in parts of Comanche, Brown, Coleman, Erath, Eastland, Callahan, Palo Pinto, Stephens, Shackelford, Young, and Archer counties. Inasmuch as the accumulation of oil and gas in this area has been due to the presence of the Bend arch, these fields will be described as belonging to the Bend Arch petroliferous province. Figure 133 shows the location of these pools with reference to the main tectonic elements in central and eastern Texas. These fields produced a total of slightly over 285,000,000 barrels of oil from 1914 to the end of 1929. Stephens County accounted for 116,000,000 of this total.

The first wells in this part of Texas were drilled shortly after the Petrolia and Electra fields had been found. No important production was secured, however, until 1914, when small, shallow wells in Schackelford and Palo Pinto counties began to produce oil. The first deep well which really opened the whole region to one of the most extensive and perhaps most tragic drilling campaigns that the oil industry has ever witnessed, was completed on Oct. 30, 1916. It was the Texas Company's No. B.-1 J. W. Parks, located southeast of Breckinridge, in Stephens County. This well came in for 75 barrels at a depth of 3,250 feet. Because of the depth to which the drill had to be carried and the relatively small production, the well did not attract the attention of the oil fraternity immediately, and it was a year later before the next deep well was completed. In October, of 1917, the Texas and Pacific Coal and Oil Company completed No. 1 McClesky at 3,484 feet for 300 barrels initial production. This well opened the famous *Ranger* field in the northern part of Eastland County. At the time this well was completed, land within a radius of from 2 to 3 miles could be bought for $50 an acre. A few months later, the same ground commanded $800 to $1,500 an acre and drilling started on a large scale.

Within 3 years Eastland County alone had produced 25,000,000 barrels of oil and Stephens County was a close second. In May, 1920, the largest well in the whole province was drilled. It was called No. 2 Stoker and was owned by the Gulf Production Company. The Stoker tract lies 2 miles south of Breckinridge in central Stephens County. This well came in for 15,000 barrels

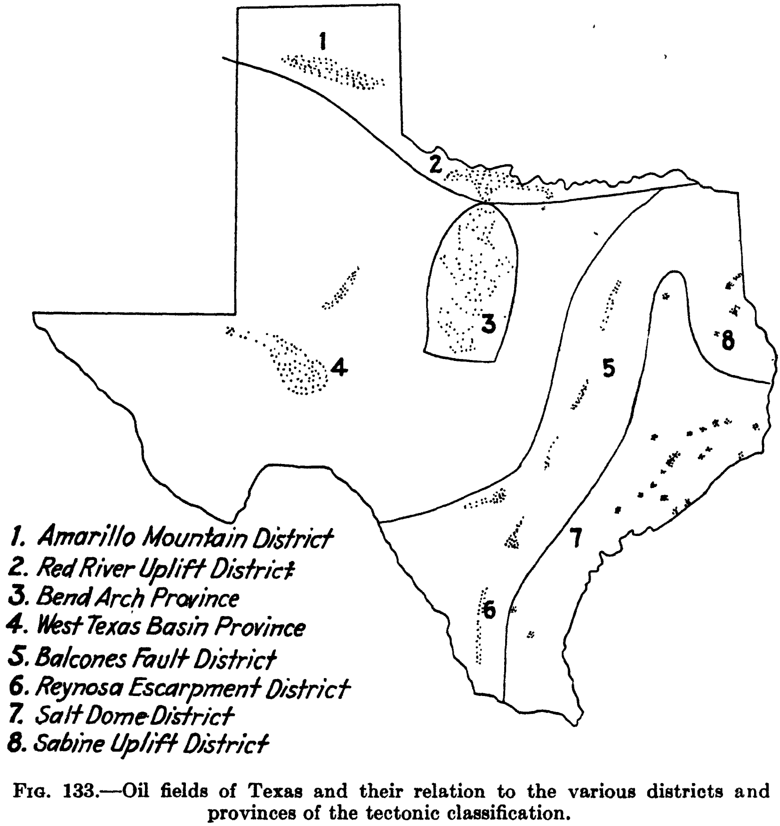

FIG. 133.—Oil fields of Texas and their relation to the various districts and provinces of the tectonic classification.

per day at a depth of 3,300 feet. Like most of the black-lime wells, however, it was short-lived.

Southern Stephens and northern Eastland counties proved to be the best oil territory, eventually, after much drilling had been done in all directions and much money had been spent in exploration. It is probable that more money was wasted in this area in drilling dry holes, and wells with small production, than in any other oil field of the country.

Tectonic Elements.—The controlling tectonic element is the Bend arch. It is not shown in the surface strata but is clearly indicated in the structural attitude of the members of the lowest Pennsylvanian strata, which are called the "Bend formation" and hence the arch is called the "Bend arch." Figure 134 shows the general outlines of the arch and also the pitch toward the north. It will be noted that the rocks of the Bend series crop out in San Saba County and gradually pitch toward the north, reaching a depth of about 3,000 feet below sea level in southern Young County. The axis of this arch passes through Brownwood, Cisco, Breckinridge, and Eliasville, The dip on the west flank is gentle and amounts to about 40 feet per mile while the dip on the east slope is somewhat less or about 30 feet per mile. The northward pitch of the fold averages 35 feet per mile. Figure 134 indicates that the arch is modified considerably at some places by terraces and cross-folds. One such cross-fold may be seen in southeastern Eastland County. This has been called the Gorman anticline and extends from Cross Plains through Rising Star, Sipe Springs, Gorman, and Desdemona. Important oil production has been found on this fold especially in the vicinity of Desdemona. Another small pitching anticline is located near Ranger in the northern part of Eastland County. This fold is not shown in Fig. 134. At Caddo, in the eastern part of Stephens County, and at Ivan, in the northeastern part of the same county, there are similar folds along the east side of the arch. A broad domal terrace will be seen in the figure between Breckinridge and Ranger.

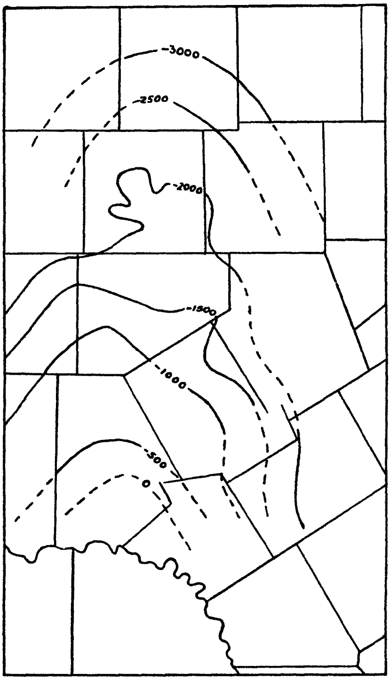

FIG. 134.—Generalized structure map showing dip of Bend series. Contours drawn on top of Marble Falls limestone. (*Univ. of Tex. Bull.* 2132, p. 199, Fig. 17.)

This is one of the largest structural modifications found on the arch and may explain the great production which has been taken from this part of the fold. These minor structures superimposed on the Bend arch do not seem to be very pronounced at the surface. In many cases very small northeast plunging noses appear in the surface beds immediately over the more pronounced subsurface features and they serve as a guide to geological explorations.

The structure of the rocks above the Bend series is exceedingly simple and may be described as a monocline with a gentle dip to the northwest, or west, averaging perhaps 35 feet per mile. In certain zones this west dip is interrupted by small terraces or small noses. Rarely do these structures have a reverse dip and a dome is very rare. The noses are in most cases two to three miles long and about one-half to three-quarters of a mile wide. Examples of such noses may be found on the published map of the Lacasa area described by Ross[1] or in the Wiles area of the Ranger district described by Dobbin[1] and the Ranger district described by Reeves.[1] In Young County, according to Cheney,[1] the outcropping strata are more strongly folded than is common in this part of Texas and no less than five pools have been found under such surface noses.

The origin of the slight surface folds and the larger folds superposed upon the Bend arch is not easily explained. Plummer and Moore suggest a number of alternate hypotheses the two chief ones of which are as follows: The Bend arch was produced by the upward movement of the relatively light acidic masses in contrast to the settling of the heavier basic masses in adjacent areas. The belts of gently folded strata at the surface and the small faults were produced by local adjustments due to relief of stress and to slight movements along old lines of weakness in the competent strata below. It seems that the explanation for the Bend arch is unnecessarily cumbersome and far reaching. A simpler explanation would be that unequal subsidence into the ancestral Gulf embayment had produced a rather steep eastward dipping monocline. Later, this monocline was tilted toward the west. (In this connection see the Fig. 87 on p. 229.)

Stratigraphy.—In Fig. 134, the areal geology of this part of Texas is shown as well as the structure of the Bend series. It will be seen that Pennsylvanian rocks (shown in white) are the

[1] See Bibliography.

prevailing rocks in the province. They have been exhaustively described by Plummer and Moore[1] in a bulletin of the University of Texas published in 1921. They classify the rocks according to the following table:

CLASSIFICATION OF THE TEXAS PENNSYLVANIAN

Brazos River Valley

Series	Formation	Thickness, feet	Description
Cisco	Putnam	175 to 200	Shale and thin limestone. Junction bed at top
	Moran	175 to 300	Shale and thin limestone. Sedwick limestone at top
	Pueblo	100 to 180	Shale and thin limestone. Colorado limestone at top
	Harpersville	175	Shale, sandstone, thin limestone, and coal
	Thrifty	100 to 150	Shale and thin limestone. Breckenridge limestone at top
	Graham	350 to 550	Thick sandy shale, sandstones, conglomerate, and thin limestones
Canyon	Caddo Creek	100 to 175	Sandstones, shale, and persistent Home Creek limestone at top
	Brad	175 to 325	Shale, sandstone, and limestone lentils with cherty Ranger limestone at top
	Graford	400	Massive limestone and thick sandy shale. Adams Branch limestone at top
	Palo Pinto	50 to 100	Massive light to dark limestone. Thins to southward
Strawn	Mineral Wells	600 to 750	Massive, coarse sandstone, sandy shale and and a few thin impure limestones
	Millsap	800 to 3,000	Dark blue to black shale, few limestones and light sandstones, coal at top
Bend	Smithwick	100 to 600	Dark fissile, sandy shale
	*Marble Falls	700 to 800	Dark gray and black crystalline limestone with thick beds of black shale. Oil
	Barnett shale	(?)	Not known, but probably present
Ordovician	Ellenburger		Light-grey and white massive limestone

[1] See Bibliography.

Bend Series.—The Bend series is a name proposed by Cummins for the lowest strata of Pennsylvanian age. It was named from the big bend in the Colorado River in the eastern part of San Saba County locally referred to as McAnnelly's Bend. The series is roughly divisible into two parts, one consisting essentially of limestone and the other of shale. The former is called the "Marble Falls limestone" and the latter the "Smithwick shale." Below these two there is a similar shale which may be of Pennsylvanian age also, but which some geologists class with the Mississippian. This is called the "Barnett shale." Inasmuch as this series is the important oil-bearing zone of the central Texas province, each of its members will be briefly described.

The *Barnett shale* was previously called the Lower Bend shale. It was named from Barnett Springs, which is about 5 miles east of San Saba, and near which it is typically exposed. Here the maximum thickness is 50 feet, but it is variable within relatively small areas. The shale is recorded in nearly all the well logs where wells have been drilled to the proper depth to reach it. It is a black, fissile shale. Girty is inclined to believe that the few fossils which have been found in it indicate that it is of Mississippian age[1] but Moore[1] believes that its stratigraphic relations are more closely affiliated with the overlying Bend formations and prefers to include it with the Bend series.

The *Marble Falls* limestone was named by R. T. Hill, in 1889, from exposures in the vicinity of the town of Marble Falls on the Colorado River not far from McAnnelly's Bend. The average thickness on the outcrop is 400 to 500 feet. It is a thickly bedded, finely crystalline, dark-grey to black limestone. Some of the layers are distinctly black and bituminous. To the north of the outcrop, according to well records, it appears to become thicker and much more shaly. The limestone becomes black shale and in the northern counties of the province, Eastland and Stephens, it is difficult to separate the Marble Falls from the Smithwick shale above it for this reason. Observations on the microscopic character of the limestone have been published by Udden and Waite[2] which show that it is a fine-grained, semi-crystalline rock, varying from wholly crystalline to granular and subcrystalline. The fossils found in the Marble Falls

[1] See Bibliography.

[2] *Bull.* A.A.P.G., **3**, 334–344, 1919.

limestone have both Mississippian and Pennsylvanian characteristics. The fauna is similar in composition to that of the Morrow formation of Oklahoma and Arkansas.

The *Smithwick* shale was named by Sidney Paige, in 1912, from the town of Smithwick located southeast of Marble Falls. He described it as a zone of black, slaty shales from 200 to 400 feet thick below the sandstones of the Strawn series, and conformably overlying the Marble Falls limestone. In the area where it crops out, the Llano Burnet quadrangle, it is a hard, dense, black, finely laminated, brittle, fissile shale containing fragile calcareous concretions, ferruginous seams and ferruginous concretions. The upper portion is somewhat sandy and often yellow-green or brown which makes it difficult to separate it from the Strawn above. According to the well records, the average thickness of the formation is 450 feet and it is found throughout the whole province. Inasmuch as it has an unconformity above it, the thickness varies considerably from place to place on the axis of the arch. On the flanks of the arch it becomes thicker. In one well some distance east of the axis, it measured over 700 feet thick. The fossils from the Smithwick indicate a closer association with Pennsylvanian species than with Mississippian forms, and Moore believes that it is contemporaneous with some of the clastic sediments which succeed the Wapanucka limestone in southern Oklahoma. (See correlation table on p. 236.)

Upper Pennsylvanian Strata.—The upper Pennsylvanian strata are separated from the Bend series by a pronounced unconformity as may be seen in Figs. 135 and 136. Above this unconformity, coarse clastic sediments were laid down at first, followed by more calcareous sediments later, and finally by muds and calcareous materials. The three series into which the upper Pennsylvanian is divided were first differentiated by Cummins, and his grouping was followed as far as possible by Plummer and Moore when they published the results of their findings.

The *Strawn* series includes all the strata from the top of the Smithwick shale to the base of the Palo Pinto limestone. It consists of beds of calcareous blue and grey shales, sandy shales, thin sandstones, and massive sandstones, some of which are locally conglomeratic. The sandstones are more concentrated in the lower portion of the series. The thickness is quite variable due

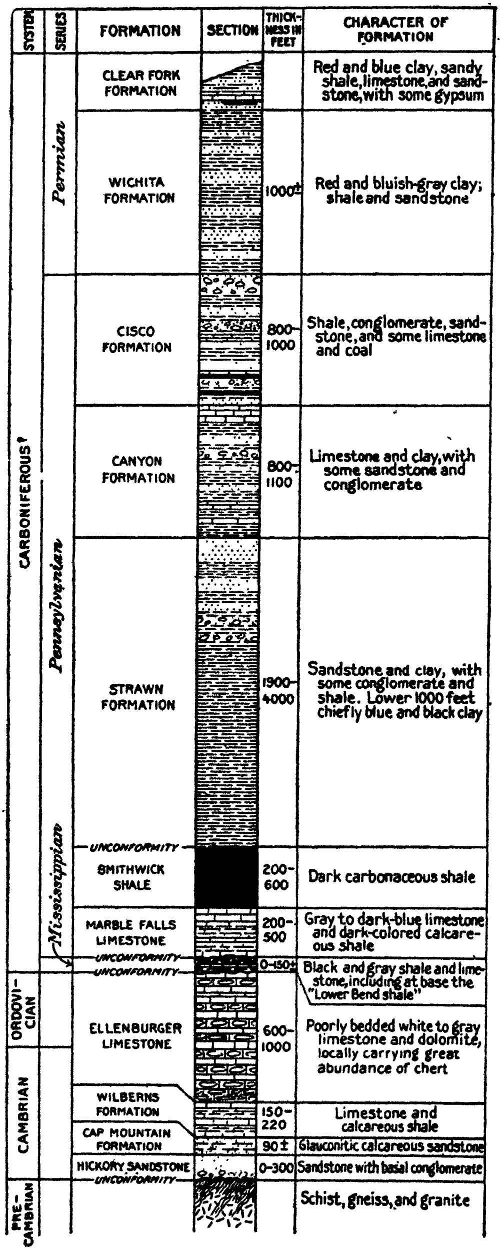

FIG. 135.—Generalized columnar section of formations in north-central Texas. (*After Rogers, U. S. Geol. Survey, Prof. Paper* 121.

to a progressive overlap from the east. In the vicinity of Brownwood, in Brown County, the total thickness is scarcely 1,200 feet, whereas on the outcrop farther east it is more than 3,800 feet. Not only do the lowermost beds disappear from the east toward the west, but also the sandstones are replaced by shales and thin limestones in that direction. Figure 136 shows the change in thickness very well and also the fingering out of the individual beds from east to west.

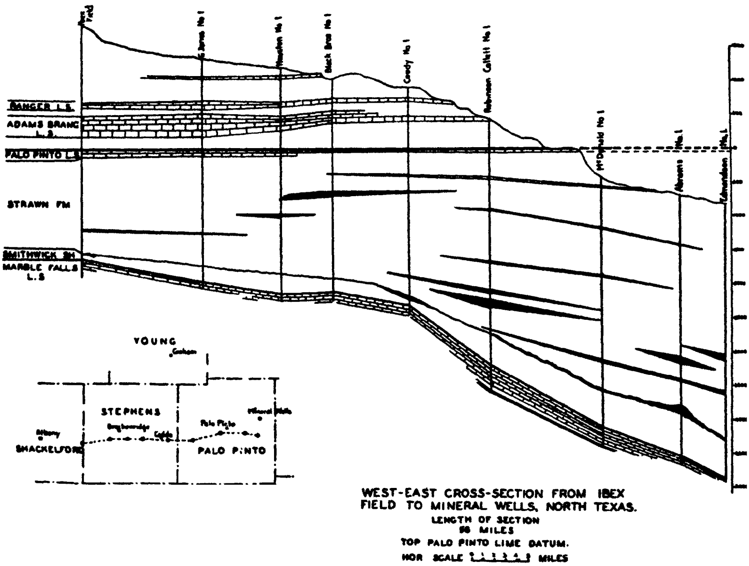

FIG. 136.—Cross-section through north-central Texas using the top of the Palo Pinto limestone as a level datum. (*After Levorsen and Plummer and Moore, Bull.* A.A.P.G., **11**, 676, Fig. 11.)

The *Canyon* series were named by Cummins after the town of Canyon on the Texas and Pacific railroad 4 miles west of Strawn in southwestern Palo Pinto County. It is an appropriate name, for along the outcrop are high, steep escarpments into which streams have cut deep canyons. The Canyon includes all the strata between the Palo Pinto limestone at the base and the Home Creek limestone at the top. It is distinguished from the Strawn and the Cisco by the greater prominence of limestones in the section; otherwise it consists chiefly of shales. The basal limestone—the Palo Pinto—is a dark-grey crystalline limestone which has a thickness of 50 to 100 feet. This is an important

horizon marker in subsurface correlations as it is the lowest thick limestone above the Bend. It is thought to be equivalent to the Calvin series in south-central Oklahoma and this in turn is equivalent to the well-known key horizon of northern Oklahoma called the "Fort Scott limestone." The fact that these widely separated limestones thus occupy approximately the same stratigraphic horizon makes it possible to compare the strata above and below in three different provinces. The Canyon is believed to be comparable as a whole to the Wewoka and associated formations of Oklahoma, or approximately from the Calvin to the Holdenville, which in turn appears to represent the Marmaton of Kansas (see Fig. 63 on page 175).

The *Cisco* series was named by Cummins from the town of Cisco in Eastland County. It includes all the beds between the Canyon and the Coleman Junction limestone, consisting of sandstones, shales, and limestones with some thin coal seams. Most of the sandstones are found in the lower portion of the series. The shales are more calcareous, lighter colored, and thinner than those in the series below, also, some streaks of red, yellow, and purple appear in them which is a rare feature in the lower ones. The Cisco has been divided into six formations by Plummer and Moore, the names of which are shown in the classification table on the preceding page. Inasmuch as no important production has been obtained from the formations of the Cisco series, they will not be described in detail.

Permian Rocks.—It appears from the studies carried on by a number of paleontologists that no sharp line can be drawn between the Pennsylvanian and the Permian. There is a very gradual gradation from one to the other, both stratigraphically and faunally. The persistent Coleman limestone is therefore as good a marker as can be found. Above it, Cummins described some limestones and shales which he found in the Brazos Valley under the name of *Albany* series. Later he found that his Albany series covered approximately the same stratigraphic section as the Permian red beds along the Red River, which had been called the Wichita series, and the name Albany was therefore dropped. More recently geologists working in northern Texas have found it convenient to retain both names because of the great difference in the appearance of the rocks in the two areas. The Albany is made up of white, escarpment forming limestones and marls, which contrast sharply with the

typical soft, red bed facies of the Wichita series. These beds lie to the west of the petroliferous area of this province and therefore will not be described further. They contain no sandstones in this area, but farther north in the Red River area of Texas, it will be remembered they do have sandstones which are the source of considerable oil and gas.

Producing Horizons.—Because of the pitch of the Bend arch toward the north the Pennsylvanian strata also are found to dip toward the north. In other words, the strata which crop out on the surface in Brown County at the southern end of the province are of lower Canyon age and the strata which crop out at the northern end of the province in Young and Archer counties are of Cisco age. The Cisco rocks begin to appear in Brown County and dip northward as far as southern Stephens County. Here they reverse their dip because of the dome in Stephens County, so that the section in northern Stephens County shows only the basal 300 feet of Cisco. From northern Stephens County the subsurface dip is quite pronounced so that by the time the northern edge of Young County is reached, 1,600 feet of the Cisco series are present in the section. This change in the thickness of the section from place to place makes a great difference in the number and position of producing horizons. In a general way it may be said that the southern end of the province derives its oil chiefly from the Bend series and the northern end of the province (Young and Archer counties), derives its oil chiefly from the Cisco series.

By far the greatest amount of oil has been taken from the Marble Falls limestone of the Bend series. At Breckenridge, in Stephens County, the Bend series has a thickness of 1,185 feet. Nearly all deep wells show 200 feet of Smithwick shale, below which there is 40 to 50 feet of limestone which has porous zones or streaks in it containing oil. The upper porous zone in the Marble Falls limestone is the *chief producing horizon* of the Bend Arch petroliferous province. About 200 feet lower there is another porous zone in the same formation, but this is not so important near Breckinridge. At Ranger, which is the best producing area in the whole province and is located in the northern part of Eastland County, the first porous zone in the Marble Falls also yields considerable oil after it has been shattered by an explosive. But the main producing zone in this area lies 190 to 200 feet below the top of the black limestone and is called the

"Ranger sand." The term "sand," of course, is merely a driller's term, for an examination of the sand shows that it is composed of limestone. This limestone, however, is somewhat peculiar. It shows cavities and vugs a fraction of an inch in diameter, lined with perfect crystals of quartz as well as some quartz veins. The storage of oil in the Marble Falls limestone, therefore, depends upon the porous condition within the limestone, which is only found in certain zones. Some of the Ranger sand, when examined under the microscope, is seen to consist of small quartz crystals and fragments of such crystals. In Brown County, Bend produc-

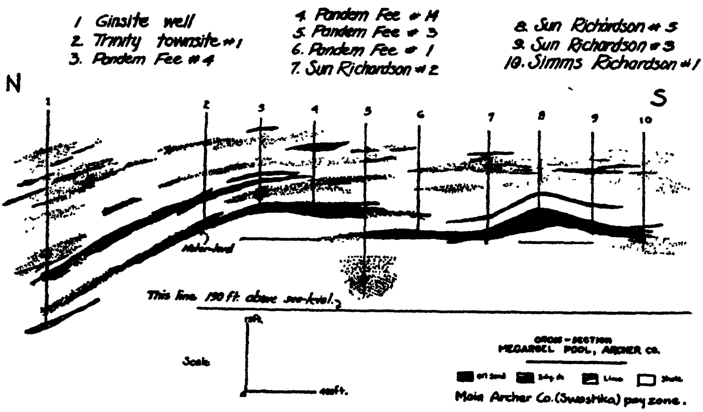

FIG. 137.—North-south section of the producing zone in the Megargel field of Archer County. (*After Thompson and Hubbard*, A.A.P.G. *Symposium*, 1.)

tion is found at a depth of 1,800 to 2,100 feet; in Eastland County, at about 3,000; in Stephens County at about 3,200 to 3,600 feet; and in southern Young County at 4,000 to 4,200 feet. Figure 137 brings out nicely the position and character of the producing zones in the northern part of the province and the character of the overlying and underlying formations.

In the formations above the Bend series some oil is found, but usually in small quantities. The producing horizons are very erratic and can seldom be traced for any distance from well to well. One of these horizons lies in the Smithwick shale and is called variously the "False black lime," the "Caddo lime," and the "Breckenridge lime." It has produced considerable quantities of oil in Stephens County. This horizon lies about 300 feet above the Marble Falls limestone.

In the Strawn series, some oil has also been obtained. In the Ranger field in northern Eastland County three sands have been named from this series. They are the Ray, found 1,850 feet above the Marble Falls limestone; the Scott, found 1,600 feet above the same datum; and the Harris, found about 1,250 feet above the Marble Falls limestone. These sands were named after the leases on which important production was first obtained in them. They vary in thickness from 10 to 75 feet and are very patchy in their distribution (Fig. 137). The production may be fairly large initially, some wells with a 1,000-barrel production having been reported from them, but most of the wells produce less than 100 barrels when first drilled into the sand. The production in western Palo Pinto County near Strawn is largely derived from approximately the same horizons. All areas which produce oil from these or similar horizons in the Strawn cover small areas usually less than 200 acres.

In Young County and farther north in the province these sands take on added importance because of the great depth to the Marble Falls limestone and some fair-sized pools have been opened in them. In the South Bend pool, for example, in southern Young County, commercial wells have been obtained from six distinct sands of the Strawn formation. These are found at depths of 1,848, 1,898, 2,106, 2,545, and 3,019 feet. Cheney reports that the first, second, and fourth of these sands have proved to be productive over the widest area and that the third, fourth, and fifth are the most prolific.

The fields of northern Young and southern Archer counties are located somewhat apart from the rest of the pools in the province. This is due to the fact that the sands in the Strawn formation pinch out in that direction, the Bend series gets very deep, and the Canyon has no sands in it. This set of conditions produces a sort of dry belt between the main part of the province and the northern end of the producing territory. In southern Archer County, the Cisco is at the surface and is about 1,700 feet thick; in the northern part of the county the Permian red beds are at the surface and the Cisco is 2,300 feet deep at the base. The production at the northern end of the county is grouped with the Ouachita-Amarillo province, the production at the southern end seems to be more closely related to the Bend Arch province. The largest pool in southern Archer County is the Swastica pool in the southwest corner of the county. Other pools nearby are

called the Miller, Gambrell, Carey, and Litchfield. Production in these pools is from sands in the Cisco series at depths ranging from 940 to 1,425 feet. As a rule, only one sand is productive in any one area and these sands cannot be traced with certainty from field to field, although it is possible that some may be the same. Most likely they are lenses which do not extend from pool to pool but pinch out between them (Fig. 137).

Relation of Production to Structure.—The structural features which are found on the surface in this province are almost without exception small noses or pitching anticlines of small size and with a pitch toward the northwest or northeast, depending on what side of the arch they happen to be located. Such noses often become accentuated in depth to more prominent noses, or even small domes with some reverse dip. Illustrations of such conditions may be found in the Ranger field where the Hope anticline, for example, shows 150 feet of closure on the top of the black lime (Marble Falls), whereas on the surface only a gently punging anticline was mapped. This is perhaps an extreme case, for other anticlines in the same area do not show nearly so much closure.

In some parts of the area there does not seem to be very much correspondence between the surface structure and the subsurface structure. The Harmel and Stampfli-Roberts pools of southwestern Archer County illustrate this condition very nicely. Hubbard and Thompson's article on the fields of Archer County shows that two pronounced folds lie at either side of the Harmel and Stampfli-Roberts pools, but the high point of the subsurface structure (and the best part of the production) lies immediately below the lowest area on the surface. Of a list of twenty-two surface folds in this county, drilling has shown that seven overlie subsurface lows, five overlie normal subsurface areas, and only five are above subsurface highs (Fig. 138).

Production is quite commonly associated with subsurface anticlines or domes. These domes may or may not be structural features. Some undoubtedly are, and this applies especially to the largest ones. Some, however, are merely reflections of difference in the thickness of the sand. In some pools, it has been noted that edge wells have no sand at all or very little of it, while wells toward the center of the field have a considerable thickness of sand.

Taking the province as a whole it may safely be concluded that accumulation has taken place according to the structural theory. The great prominent subsurface fold—the Bend arch—has served

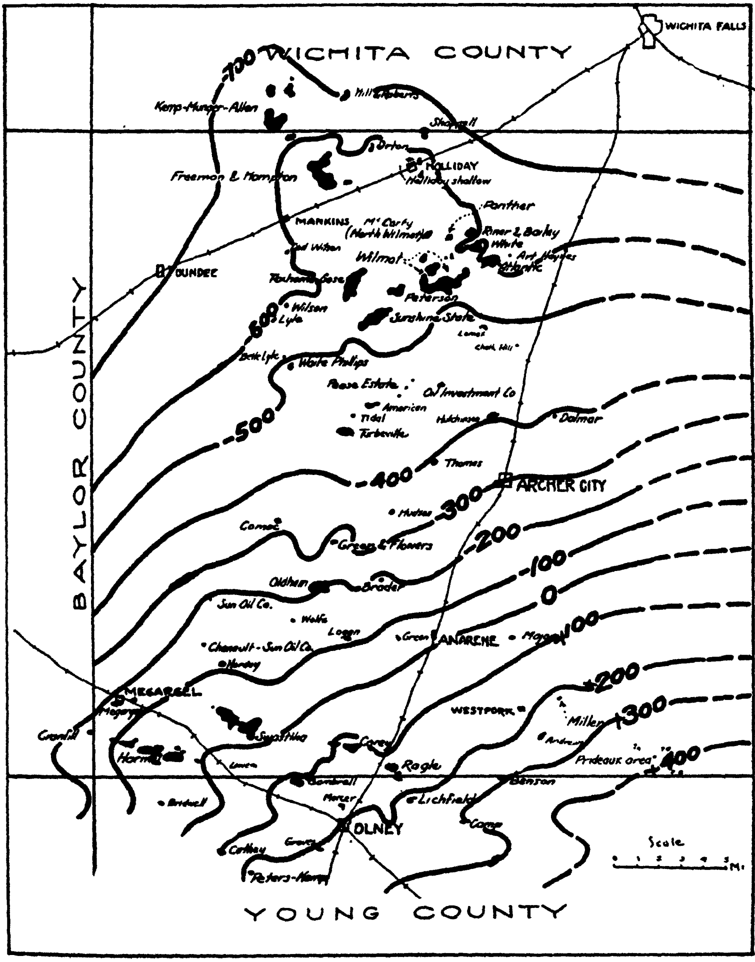

FIG. 138.—Index map of pools in Archer County and generalized structure of the main pay sand. (*After Thompson and Hubbard*, A.A.P.G. *Symposium*, **1**.)

to collect much oil from the flank basins and this was concentrated near the highest parts of the fold. Its distribution near the axis of the fold, however, does not depend so much on minor structure as it does on the differential thickness of the sand in cases where a true sand reservoir exists. In cases where the

reservoir is a porous limestone, and perhaps 90 per cent of the oil is derived from such reservoirs, the differential porosity has been the determining factor.

This is strikingly illustrated in the Ranger field. One of the important producing horizons is called the "McClesky sand." It was described above as the porous zone in the Marble Falls limestone which lies approximately 200 feet below the top of the limestone. The McClesky sand has a thickness of 30 to 50 feet where the production is greatest and the whole producing area lies within the area where the sand is at least 25 feet thick. Where the sand is thinner than 25 feet, either small wells or dry holes are the result of drilling. The thickness in this case is a measure of the porosity, and where the porosity amounts to a zone 25 feet or more in thickness, oil in quantity has collected and when such porous zones coincide with high structural conditions the best yields are obtained.

Production Statistics.—Of the ten counties in this province, Stevens has produced the most oil, amounting to 116,000,000 barrels up to the end of 1929. Eastland County, including the rich Desdemona pool which lies in the eastern part of the county and overlaps into adjacent Erath and Comanche counties, had produced over 89,000,000 barrels up to the end of 1929. The rest of the counties produced about 80,000,000 barrels during the same time. The gravity of the oil ranges from 35 to 40° Bé., the lower gravity being found chiefly in the upper sands and the better quality oil in the black-lime sands. Very probably the oil in the Bend series had its origin in the black shales with which it is associated. The oil in the Strawn formation may have migrated up from the Bend series. Some of the shales in the Strawn are black and these shales may have produced some oil.

One of the important features of the production in this province is the rapid decline of the wells. Some of the largest wells produced all or most of their oil during their first year. Wells having an initial production of 8,000 to 11,000 barrels per day were pumping only 50 barrels at the end of the year. It has been estimated that the Ranger field will have an average production of less than 1,000 barrels per acre, although some leases on which early wells were drilled may run as high as 3,500 barrels. The maximum production of the Ranger field was reached in the second week of July, 1919, when it produced 80,000 barrels per day. A year later, however, this production had dropped to

only 20,000 barrels per day. In 1927, the total production from the whole county in which the Ranger field is located had dropped to 9,000 barrels per day.

Salt water seems to be present in every sand. It is found abundantly in the sands of the Canyon and Strawn series, but is not so abundant in the sands of the Bend series. In the Ellenburger limestone of Ordovician age, which is found everywhere below the Bend series, water is very abundant and always occurs in large volumes when the drill enters this formation.

Gas has been found with the oil in nearly every part of the province. It furnished the propulsive force of the early gushers, but was allowed to escape and, therefore, the pressure in the main field went down rapidly. One of the main areas which produces only gas is the Mineral Wells field in eastern Palo Pinto County, another is located a few miles southwest of Strawn in the southwestern corner of the same county. Several smaller fields are located in eastern Stephens County.

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CHAPTER VIII

THE GULF EMBAYMENT PROVINCE

The oil fields of Texas belong to four different petroliferous provinces. The oil pools of the northwestern part of the state and the pools of the north-central part of the state have been described in Chap. VI, and the oil pools of the central part of the state were treated in Chap. VII. During the last few years,

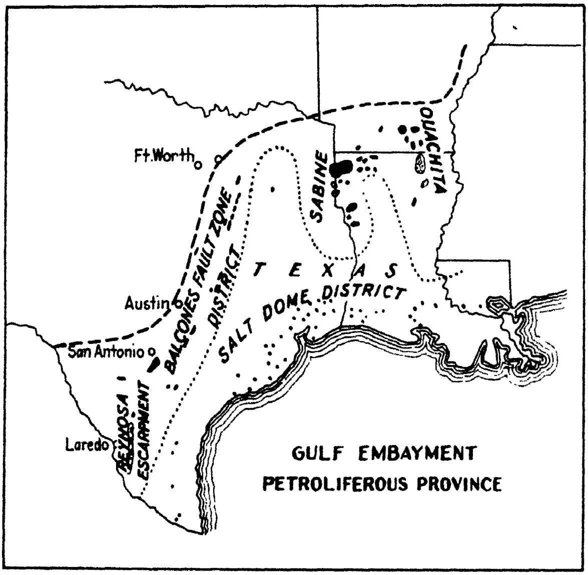

FIG. 139.—Gulf Embayment petroliferous province. Solid black indicates oil pools; stippled areas, gas pools; and scattered dots, productive salt domes. Province outlined by dashes.

large pools with an immense reserve of oil have been discovered in western Texas. These will be treated in a later chapter. There remain four other districts in the state which are important producing areas. They will be called the Balcones Fault district (or east-central Texas), the Northeast Texas district, the South Texas district (Reynosa Escarpment district), and the Salt Dome district of southeastern Texas. These four districts are related tectonically and will therefore be considered as a

group together with related fields in adjacent states under the heading of Oil Fields of the Gulf Embayment Province.

The Gulf Embayment province includes portions of three states Texas, Louisiana, and Arkansas. The component districts in Texas have already been enumerated. In Louisiana there are three separate districts which belong to the province, the Sabine uplift district, the northeast Louisiana (Ouachita uplift) district, and the Salt Dome district. In Arkansas there is an area in the south-central part of the state which has produced large amounts of oil, and this also will be included in the province. Each of these districts will be taken up separately. Before considering the first district a survey must be made of the province as a whole in order to get the proper structural background.

Tectonics of the Gulf Embayment.—The Gulf embayment as constituted at present covers a large area, including portions of eastern Mexico, eastern Texas, southeastern Oklahoma, Arkansas, Louisiana, and the states east of the Mississippi adjoining Arkansas and Louisiana. In Fig. 140, most of this area is shown and some of the controlling tectonic elements. These are (1) the Choctaw fault in southeastern Oklahoma, which bounds the Ouachita Mountains on the north and west; (2) the Mexia fault zone, which is the important controlling element in the first district studied; (3) the Steen-Palestine fault zone in northeastern Texas; (4) the Balcones fault line (which has given the name to the first district although no important oil fields are directly associated with it); (5) the Luling fault line which is a continuation of the Mexia fault zone; (6) one of the many fault zones in the coastal salt-dome district; (8) a similar fault zone, in the salt-dome district in Louisiana; (9) the Webb-Zapata counties fault zone, which also is a continuation of the Mexia-Luling line; (10), (11), (12) and (13), fault zones in Mexico.

From this imposing array of fault zones one is likely to get the impression that the Gulf Embayment province is characterized by lines of faulting instead of lines of folding, such as were described in the preceding chapters. This impression is entirely correct. Practically all the districts in this province are traversed by faults even though we may not always have indisputable evidence of faulting; nevertheless folds are also present and folding has been influential in certain districts in causing the accumulation of oil. Faults, then, are the critical elements in the tectonics of the province and folds are subordinate.

It will be noted that the faults which are shown in Fig. 140 constitute a more or less symmetrical series facing the Gulf of Mexico. The reason for this is that they have a common origin. Broadly speaking, it may be said that all the faults are the result

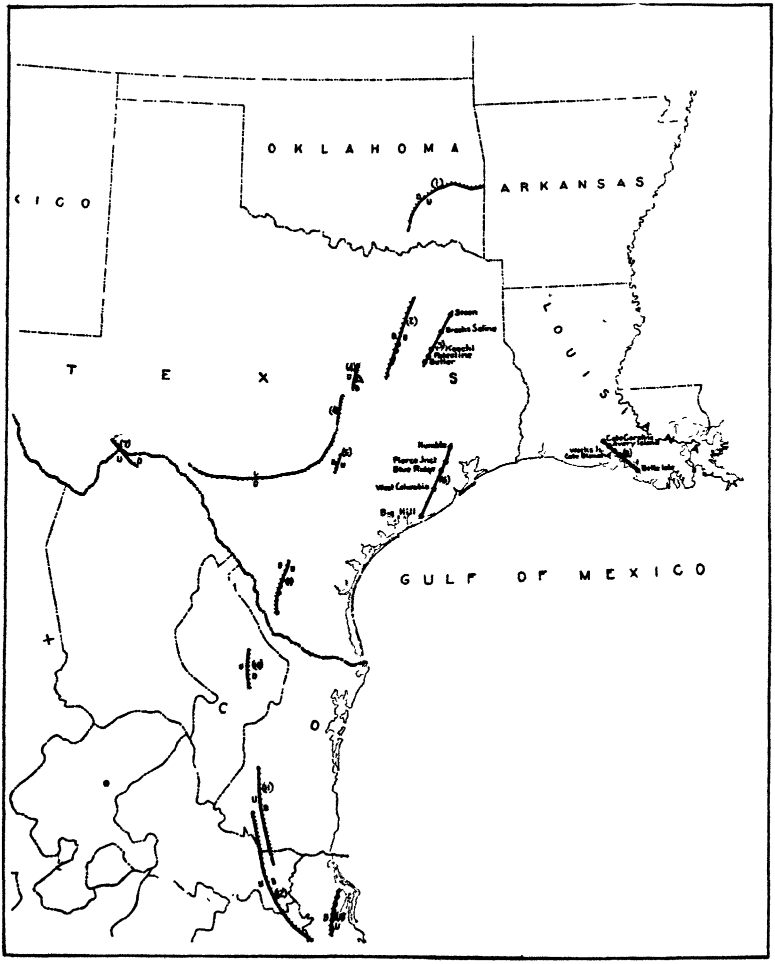

FIG. 140.—Map showing structural lines in the Gulf coastal area. (*After Pratt and Lahee, Bull.* A.A.P.G., **7**, 228, Pl. II.)

of the sinking of a large land mass, called "Llano" or "Llanoria" (see Fig. 5). The sinking of this segment of the earth's crust caused tension faults to form around the periphery and especially along certain lines of weakness. The first movements probably

started in early Paleozoic time and possibly in pre-Cambrian time. Lines of separation, established then, persisted through later geologic periods and renewed movement took place along the same lines again and again. Some of the periods of profound movement may be read from the geologic record in the Ouachita Mountains and the Llano-Burnet uplift (or Central Mineral district) of Texas (see Fig. 141). The Choctaw fault in southeastern Oklahoma was made after the youngest Paleozoic rocks of that region had been formed. It is, therefore, post-Glenn, or later than early Pennsylvanian, but it does not cut through the Cretaceous rocks; therefore, it is pre-Cretaceous. This fault differs in one important respect from the others; it is an overthrust fault. If the movements along a fault are analyzed they may be resolved into two components, one acting horizontally and the other vertically. When the horizontal force greatly exceeds the vertical force, an overthrust will result; but if the vertical force exceeds the horizontal or if both are nearly equal, a normal fault will result. At the same place and along the same line of weakness, the two forces may be different at different times.

In the Llano-Burnet uplift, the faults described by Paige are normal with nearly vertical displacement and are also pre-Cretaceous and post-early Pennsylvanian. They thus seem to be related to the Choctaw fault in point of time, even though one is a compression fault and the others are all tension faults. The amount of displacement in the Choctaw fault is very great and estimated as high as 8,000 feet, the displacement in the Llano-Burnet Mountains reaches a maximum of 1,800 feet. The faults in the Llano-Burnet district have a predominant trend toward the northeast, although there is considerable evidence of faulting in a direction at right angles to this trend. It will be noted that practically all the faults on the west side of the embayment have a northeasterly trend.

The Balcones fault zone has the downthrow of the rocks toward the east whereas the Mexia fault zone has the downthrow toward the west, thus producing a *graben* between the two. The Steen-Palestine fault zone has some remarkable features which set it off from the other fault zones just described. A number of small cylindrical plugs of salt appear in this zone. They are the Steen, Brooks, Keechi, Palestine, and Butler salt domes. It is difficult to explain these salt intrusions along a straight line (with one

exception) and with such a great displacement of strata, in any other way than to postulate a fault zone. In the light of the information obtained in recent years by the exploitation of the oil fields along the Mexia fault zone, this explanation no longer appears unreasonable and is now accepted by most geologists.

Stratigraphy.—The rocks which are involved in the Gulf Embayment province belong to the Comanchean, Cretaceous, and Tertiary periods. The table of formations below will give the reader an opportunity to become acquainted with the nomenclature.

TABLE OF FORMATION NAMES USED IN THE GULF EMBAYMENT PROVINCE

Periods	Central Texas	Eastern Texas	Northern Louisiana and Arkansas
Eocene	Yegua	Yegua	Yegua
	Cook Mountain Mount Selman	Cook Mountain Mount Selman	St. Maurice sparta sand Cane River
	Carrizo Indio	Carrizo Indio	Wilcox
	Midway	Midway	Midway
Cretaceous	Navarro	Arkadelphia clay Nacatoch sand Unnamed shale	Arkadelphia clay Nacatoch sand Marlbrook marl
	Taylor	Pecan Gap chalk Wolfe City sand Unnamed shale	Annona chalk Ozan formation Brownstown marl
	Austin chalk	Austin chalk	Blossom sand Tokio formation (upper Bingen)
	Eagle Ford	Eagle Ford	
	Woodbine	Woodbine sand	Lower Bingen
Comanchean	Washita series	Washita	Washita
	Fredericksburg	Fredericksburg	Fredericksburg
	Trinity series	Trinity	Trinity

Permian (?)
Pennsylvanian (?)
Pre-Cambrian igneous and metamorphic rocks

BALCONES FAULT DISTRICT

The phenomenal success which attended drilling at Mexia induced oil companies to search out other similarly located areas

in east-central Texas. The Balcones Fault zone was studied by hundreds of geologists and the parallel zone of faulting (later called the "Mexia fault zone") was slowly outlined by surface geology and by drill records during the next few years. One year after Mexia was discovered the pool at Luling was found. It also was bounded by a fault at the west, but the difference found in this pool was that the oil had accumulated in the Edwards limestone which up to that time had not been known as a producing horizon. In 1923, the Currie pool was opened up, and in 1925 the Lytton Springs pool was found. The last named pool, like the one at Thrall, encountered a buried volcano and its ejectamenta and, curiously enough, considerable oil was found in the porous part of this altered igneous rock. In 1926, the Nigger Creek pool was located which was different from the rest again. Many geologists had been led to believe that oil would only be trapped by a fault which lay along the east side of the zone. This pool proved that some oil had been accumulated along a fault which lies west of the basinward edge of the fault zone.

The fields and pools which have been discovered in the Balcones Fault zone, up to date, are as follows (beginning with the most northerly one and extending to the south): Corsicana, Powell, Richland, and Currie in Navarro County; Wortham, Mexia, and Groesbeck in Limestone County; South Bosque, McLennan County; Marlin, Rockdale-Tracy-Minerva in Milam County; Thrall, Lytton Springs, Luling, Mission, Alta Vista, Somerset, South Medina in Bexar County; Hondo, and Medina in Medina County. Of these, the largest is the Powell pool with Mexia a close second. Luling has also produced a large quantity of oil. The other pools are considerably smaller, some being quite small. Groesbeck produces gas only and some of the older pools are chiefly gas pools, as are the Corsicana, the Mildred, and the Eureka shallow pools east and west of Powell. Most of the pools lie some distance east of the Balcones Fault zone and nearly all of them are on the trend of the Mexia fault zone. The only pool which lies west of the Balcones fault is the South Bosque pool in McLennan County, west of Limestone County.

Tectonic Conditions.—The controlling tectonic feature in east-central Texas is the zone of faulting which has been called the "Balcones fault." It was first described by Hill in some of his publications on the geology of the state and has since then

been definitely proved to exist over a long stretch of territory. Associated with this fault zone and more or less parallel to it is the Mexia fault zone. Both of these zones are shown in Fig. 141 which is taken from Foley's article on the mechanics of the Balcones and Mexia faulting. The Mexia fault zone is shown

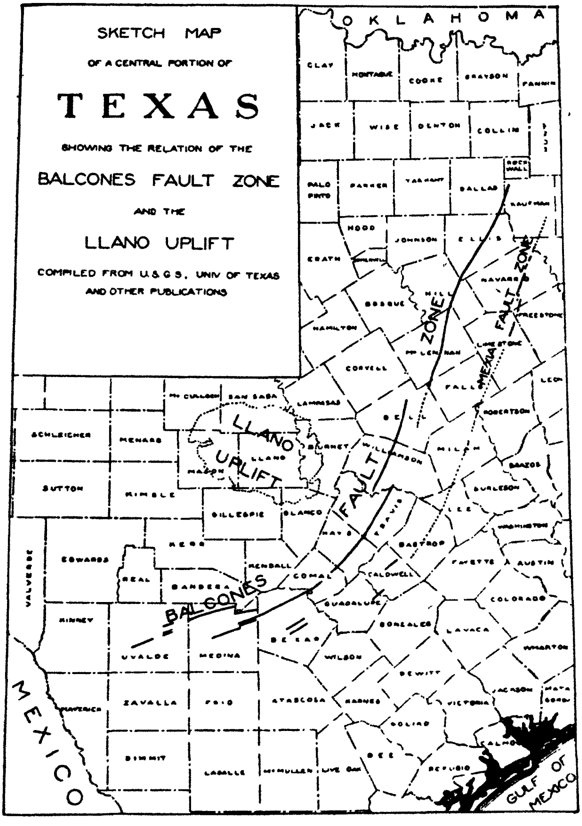

Fig. 141.—Sketch map of the central portion of Texas showing the Balcones and Mexia Fault zones and their relation to the Llano uplift. (*After Foley, Bull. A.A.P.G.*, **10** (No. 12), 1262, Fig. 1.)

with its hypothetical extension through Milam, Lee, and Bastrop counties to the Lytton Springs and Luling fields in Caldwell and Guadelupe counties and the San Antonio fields in Bexar County. On the basis of experiments Foley made to simulate these fault zones, he concludes that the Balcones and Mexia faulting was due to tensional stresses caused by subsidence in the Gulf coastal region, and that the stresses were modified by the

support of the Llano uplift causing the Fault zones to curve around the southeastern side of the Llano uplift.

The general relations between the Balcones Fault zone and the Mexia zone is brought out in Fig. 141. Fohs states that at Mexia the faults strike from N. 29° to 40° E. averaging N. 35° E., at Currie from N. 13° to 23° E., at Groesbeck from 10° to 30° E., at Kaufman from N. 25° to 54° E., and at Powell about N. 26° E. A single fault may change its strike several times, for instance, the main fault on the east side of Mexia changes its strike twice, at Currie likewise there are two or more changes of strike. The individual faults have a length of about 6 miles and where one stops another begins in an en echelon fashion. The dip on the faults varies considerably, some dip as low as 35 to 36 degrees and some as high as 63 degrees. Another interesting feature is that the dip changes on passing into different kinds of rock. As a rule, the dip is steep in the limestone, but much flatter in the shales. At places there is evidence that the fault disappears entirely in the shales and reappears at a different place in the next lower limestone. At Mexia and Currie, the dips average about 45 degrees. The vertical displacement of the outer fault at Mexia ranges from 195 to 400 feet; at Powell from 245 to 350 feet. The Mexia zone is from 5 to 9 miles wide and lies about 15 miles east of the Balcones zone.

Hill suggested years ago that the abrupt bend shown in the Balcones fault (see Fig. 140) may not be a bend at all but rather indicates the intersection of *two fault zones*, one trending nearly east and west and the other more nearly north and south. If that is the case, then the fault zone in southern Texas in Webb and Zapata counties may be a continuation of the Balcones zone.

The average rate of dip of the sedimentary rocks in the region being discussed is about 40 feet to the mile toward the southeast. This rate of dip increases somewhat locally. For instance, in Caldwell and Guadelupe counties the dip is 100 feet per mile, and in the northeastern part of those counties the average is about 150 feet per mile.

Stratigraphy.—The succession of rocks in the Balcones Fault district involves the strata of both Mesozoic and Cenozoic age. The Eocene series of the Cenozoic is represented by the Midway and Wilcox formations and the Mesozoic group is represented by the Comanchean and Cretaceous systems. These strata were evidently deposited on a very old surface of

schists and granites representing possibly Archean and Algonkian rocks. If Paleozoic strata are present they have not been definitely identified. The generalized table of formations given on next page, will aid the reader in forming a picture of the stratigraphy of this district.

Most of the pools lying along the trend of the Mexia Fault zone in eastern-central Texas lie within the outcrop band of the lowest Eocene formation—the Midway formation. A few pools,

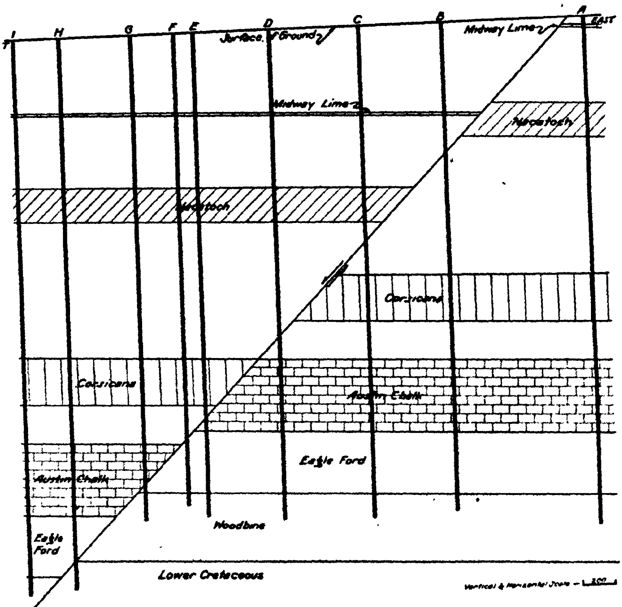

FIG. 142.—Diagrammatic section to illustrate relation of wells to formations in different position in the fault zone. (*After Lahee, A.A.P.G. Symposium,* **1**.)

like the old Corsicana shallow pool, the Powell and the Thrall pools, lie within the outcrop band of the youngest Cretaceous formation—the Navarro formation. The unconsolidated beds of sand and clay in the Midway and the Wilcox do not ordinarily play a large or important part in the well logs, except that some of the thicker limestones in the Midway are usable for shallow correlations and to measure the fault displacement at a shallow depth, which is often desirable.

In the southern part of the district, the Midway and the Wilcox formations are nearly 1,800 feet thick and consist of sands, clays, lignitic beds, and some glauconitic greensand near the base.

Generalized Stratigraphic Section for Balcones District

System		Formation	Thickness, feet	Character
Tertiary	Eocene	Wilcox	450	Sands, clays, and conglomerates with beds of lignite and some thin limestones
		Midway	300	Sandy clays, fine argillaceous sands, and some limestones
Cretaceous		Navarro	600	Calcareous clay, sandy clay, and fine lenticular beds of fine sand
		*Taylor marl	1,000	Clays, shale, and sandstone lenses. Contains oil sands of shallow Corsicana field
		Austin chalk	450	Chalky limestone with some hard layers
		Eagle Ford	350	Shales and clays with some limestone
		*Woodbine	200	Soft sandstone with beds of shale and thin streaks of lignite, quite ferruginous. Main oil sand
Comanchean	Washita	Denison	175	Clay and limestone
		Forth Worth	50	Alternating beds of limestone and marl
		Preston	75	Calcareous clay and impure limestone
	Fredericksburg	*Edwards limestone	200	White chalky limestones. Produces oil in southern part of district
		Comanche Peak	200	Limestone and chalky layers
		Walnut clay	150	Calcareous clays, some marly limestones
	Trinity	Paluxy sand	150	Sand and lenticular beds of clay
		Glen Rose limestone	400	Limestone, marls, and calcareous shales
		Travis Peak sandstone	250	Sandstone and conglomerate, some thin shales and limestones
Archean and Algonkian			1,600+	Igneous rocks and metamorphic rocks

The uppermost Cretaceous formation, the Navarro, is about 600 feet thick in the southern part of the district and consists of bluish-grey calcareous clays with occasional thin lenses of sand interbedded. In the northern part of the district, the Navarro consists of greenish-grey and yellow nodular clay with fine glauconitic sand lenses interbedded. The Taylor marl which immediately underlies the Navarro is about 800 feet

thick in the southern part of the district and consists of clay predominantly, but the clay is more calcareous than that of the Navarro and very calcareous near the base. Sandstones and limestones are practically absent. In the northern part of the district, it is very similar in lithology, but contains some beds of fine sand. The oil in the Corsicana pool, for instance, is obtained from a sand in the upper part of the Taylor marl which ranges from a few feet to a maximum of nearly 60 feet. This sand and others in the section are very lenticular.

The Austin chalk is perhaps the most important formation in the Cretaceous system because it is so distinctive both on the outcrop and in well records. It is the first reliable key horizon and for that reason is often used to draw contours of the subsurface structure. In the southern part of the district it is only 200 feet thick, but in the northern part it is 425 feet thick. Below the Austin chalk there is a variable thickness of bluish-grey to blackish shale called the "Eagle Ford shale." It is only 30 feet thick in the Luling area and 43 feet in Bexar County, whereas in the northern part of the area it is nearly 400 feet thick. This convergence of strata from north to south probably is due to overlap from the north. The Eagle Ford shale is quite commonly looked upon as the original source rock of much of the oil in the whole district, as it is markedly bituminous in places.

Below the Eagle Ford there is a great hiatus, represented in the northern part of the district by the Woodbine sand, but in the southern part of the district by an unconformity.

Comanchean Strata.—The beds below the Woodbine, of Comanchean age, are not of great interest in the northern part of the area, for below the Woodbine no production has been found, although quite a number of deep wells have penetrated the Comanchean strata. In the southern part of the area, however, the Comanchean becomes the important part of the section. The Washita series, on the north divided into the Denison, Fort Worth, and Preston beds as shown in the table on page 357, is subdivided into the Buda, Del Rio, and Georgetown formations in the southern part of the district. The Fredericksburg and Trinity series have the same subdivisions in both parts of the district. The Buda consists of hard, dense limestone 30 feet thick; the Del Rio, of bluish clays, about 50 feet thick; and the Georgetown of massive greyish-yellow limestones with a thickness of 50 feet.

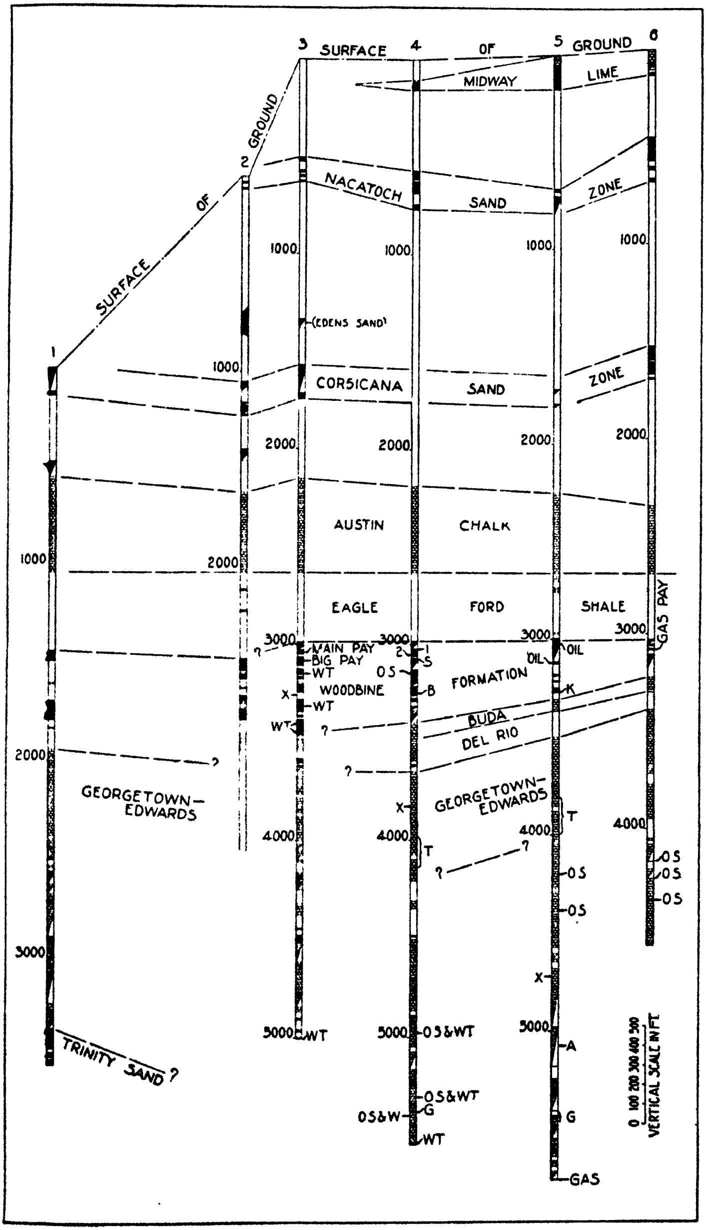

Fig. 143.—Correlation chart of logs, in Navarro and Limestone counties. (*After Lahee*, A.A.P.G. *Symposium*, **1**, 334.)

The Fredericksburg series is the series we are especially interested in, for it contains the oil-bearing horizon called the "Edwards limestone." The Edwards limestone forms the uppermost formation of the series and is approximately 500 feet thick. It is composed of massive, dense, grey, fractured limestone, contains considerable dark-colored chert, and is fossiliferous. Where this limestone is porous, it has become a good reservoir for oil (in the Luling field of Guadelupe and Caldwell counties). In Fig. 143, the rocks which lie below the Edwards limestone are shown in cross-section. The Edwards is not separated from the Comanche Peak limestone, and the typical Walnut clay, below the Comanche Peak, is evidently represented by limestone in this part of Texas or else has not been recognized by the driller. The Comanche Peak limestone in Bexar County is 75 feet thick and this, with 724 feet of limestone correlated with the Edwards, gives a total of about 800 feet for both. Only 20 feet of yellow clay belonging to the Walnut clay horizon were found in Bexar County. The Glenrose formation in the Luling field is 1,450 feet thick and consists of broken dolomitic lime, limestone, and dark shales. In Bexar County, it is 1,785 feet thick and consists of limestone of various colors; white, yellow, and grey as well as some black limestone of bituminous character. Below the Glenrose formation appears a succession of sands, conglomerates, and laminated shales and clays probably to be correlated with the Travis Peak but usually called simply "Trinity sand." These strata are about 500 feet thick at Luling and 479 feet thick in the deep well in Bexar County reported by Jones.[1] In both areas, the basal beds are very coarse and conglomeratic.

Below the Comanchean rocks, over 3,000 feet of schists were encountered at Luling, which are sericitic schists of a talcose nature. Analysis shows that they consist chiefly of silica and alumina with small amounts of other oxides. No clue is given of the age of these schists although they are most likely of pre-Cambrian age. A well in northwest Bexar County went directly from Comanchean strata into pre-Cambrian schists.[2]

Producing Horizons.—The table below gives a comprehensive idea of the stratigraphic position and character of the producing horizons in the Balcones fault district of the Gulf Embayment province. The zones which have produced the most oil are

[1] Jones (see Bibliography).

[2] See *Udden, Univ. Tex. Bull.* 1932, p. 131, 132.

TABLE OF PRODUCING HORIZONS—BALCONES FAULT DISTRICT

Formation	Sand	Description
Navarro	Nacatoch	Medium-grained to fine-grained glauconitic sand or more properly a group of sand lenses. Produce gas in Mexia and Groesbeck fields. The shallow heavy oil at Powell comes from this horizon. Sands and shale partings occupy a zone of considerable thickness
	Edens	Thin sand lens produces oil at Corsicana
	Corsicana	Zone of sand lenses separated by shales. Sand mostly fine grained. Oil at Corsicana, 500 feet above Austin chalk and 800 feet below Nacatoch
Taylor	Thrall	Porous, soft, green rock called serpentine. Altered basic igneous rock. Produces oil at Thrall and Lytton Springs
	Lytton Springs	Same kind of rock as at Thrall, but probably somewhat older, extends from base of Austin chalk 600 feet into Taylor above
Austin	Austin Chalk	Porous chalky limestone. Produces oil in Joe Bruner pool
Woodbine	*Woodbine	Series of sand lenses in Woodbine formation. Main pay at Currie and Mexia lies within 50 feet of top. "Morrow" pay at Currie lies 250 feet below main pay
Edwards	*Edwards	Soft, brown, porous, dolomitic(?) limestone. Upper portion contains oil at Luling and Joe Bruner pool. Mineralized sulphur water below oil at Luling. Fresh water farther west along Balcones fault

starred, although the others have accounted for a good deal of oil and gas also. The *Nocatoch* sand is really a zone of sandy layers or lenses in the Navarro formation which appear to lie at about the same horizon as the prolific sand called the Nacatoch in the Caddo field of northwestern Louisiana. The individual sand lenses sometimes attain a thickness of 60 feet in certain wells. The shallow gas from the Mexia field and also the gas at Groesbeck comes from this horizon. The heavy oil from the older part of the Powell field appears to come from the same or a similar horizon in the Navarro formation.

The Edens sand is not very important. It is one of the sands which produced a little oil in the early days of Corsicana. It has

not been recognized elsewhere. The Corsicana sand is of much greater importance, for most of the early production from Corsicana came from it. This sand also is a series of sand lenses rather than a single sand, the lenses being separated by shale layers. The producing zone lies about 500 feet above the Austin chalk key horizon and about 800 feet below the Nacatoch sand horizon. Production from this zone is not large, but is long lived. In 1900, 4 years after the Corsicana pool was discovered, the maximum annual production was reached and it amounted to about 800,000 barrels. The average life of a well in the pool is about 10 years.

The producing horizon at Thrall and at Lytton Springs is very interesting, because production from an igneous rock is somewhat of an anomalous condition. The rock appears as a soft, greenish mud when drilled, but careful analyses have shown that it is similar to serpentine in composition and probably a decomposed basaltic rock. At Lytton Springs, it consists of material which was in part volcanic ash and lava and in part intrusive basalt. Texturally, it is fairly hard and brittle and only locally does it become soft and form a sticky mud. It occurs throughout a range of 600 feet stratigraphically, taking in all the Austin chalk and several hundred feet of the overlying Taylor marl. This height and the rudely dome-shaped outline of the mass as a whole suggests that it was accumulated largely as a volcanic cone. Some of the material shows definite intrusive contacts between the serpentine and the chalk and there is also considerable doming of the rocks overlying the serpentine. For that reason some of it appears to be intrusive and it is possible that the whole may be intrusive. The faults shown in Fig. 144 indicate the avenue of escape of the lavas from beneath. Early in 1929, oil was found in the Austin chalk in the new Bruner pool south of Luling.

Production is obtained from the surface of the serpentine over a vertical range of 600 feet, but most of the oil is found within 200 feet of the top of the mass. A remarkable feature at Lytton Springs, and at Thrall as well, is the general absence of water. This seems to indicate that the oil had a very local source and merely was absorbed by the porous rock of the igneous mass by contact with a bituminous series of shales.

The Woodbine sand is the most important producing horizon in this district. Its nature was described somewhat fully in the

section on stratigraphy, so that only a few details are necessary here. The Woodbine sand is not a single sandstone as the name implies, but rather a series of sandy lenses with shale partings. The woodbine zone may be very thick, but usually only thin portions produce oil. At Mexia, the great production comes from very near the top of the formation. At Currie, the main pay also lies within 50 feet of the top. At other places different zones have been found productive. One quite important pay lies 250 feet below the main pay at Currie and is called the "Morrow" pay. The oil in this sandy formation is very probably indigenous to a large extent, although many geologists believe that the overlying Eagle Ford shale has contributed all or most of the oil.

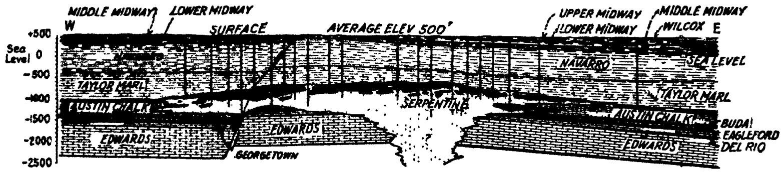

FIG. 144.—Cross-section of the Lytton Springs oil field. (*After Collingwood and Rettger*, *Bull.* A.A.P.G., **10**, 959, Fig. 3.)

The Edwards limestone is another important producing horizon and a very interesting one, because it is not usually looked upon as a likely reservoir rock for petroleum. The important pool in which this limestone is the producing horizon is the Luling pool which will be described in some detail in succeeding pages. The Edwards limestone is a hard, dense limestone, where it has been studied on the outcrop, but in the well cuttings it appears as a soft, brown, porous limestone. The brown color is due to the bituminous materials found in it, and the soft texture is due to some kind of alteration which has affected the rock after it was laid down. It may be due to dolomitization or it may be due to weathering during a time when the Edwards was subject to erosion. The latter seems to answer the conditions more closely, inasmuch as only the uppermost portion of the rock has been found to produce oil and gas. At San Marcos, where large springs issue from the limestone (or faults associated with the limestone), the water is pure and fresh, but in the Luling pool the water which occurs under the oil is highly mineralized and impure.

Typical Fields.—In order to bring out more clearly the rather unique conditions which exist in this district, several typical fields will be described in detail. One of the most interesting is the Luling field located in Caldwell and Guadelupe counties, 4½ miles northwest of Luling and 20 miles southeast of the main

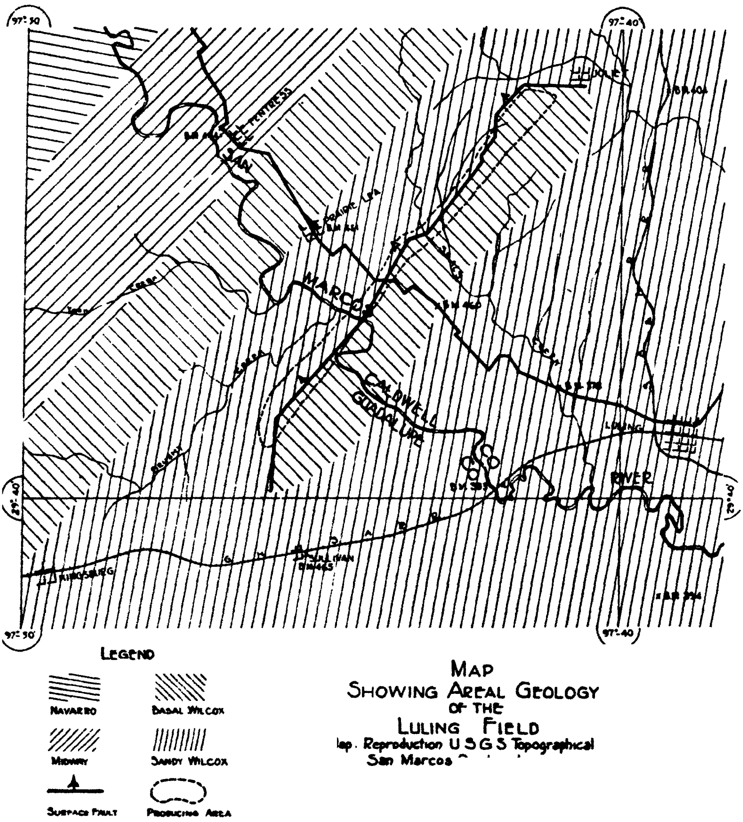

FIG. 145.—Map showing areal geology of the Luling field. (*After Brucks., Bull.* A.A.P.G., **9**, 632, Fig. 1.)

Balcones fault line. It has a length of 7½ miles and a width of 3,000 feet or less. The location together with the surface fault is shown in Fig. 145. The discovery well was drilled in 1922, oil being obtained from the top of the Edwards limestone. By the end of the next year, 30 producers had been completed. The surface beds belong to the Wilcox formation and below these strata the normal section of Midway, Navarro, Taylor, Austin,

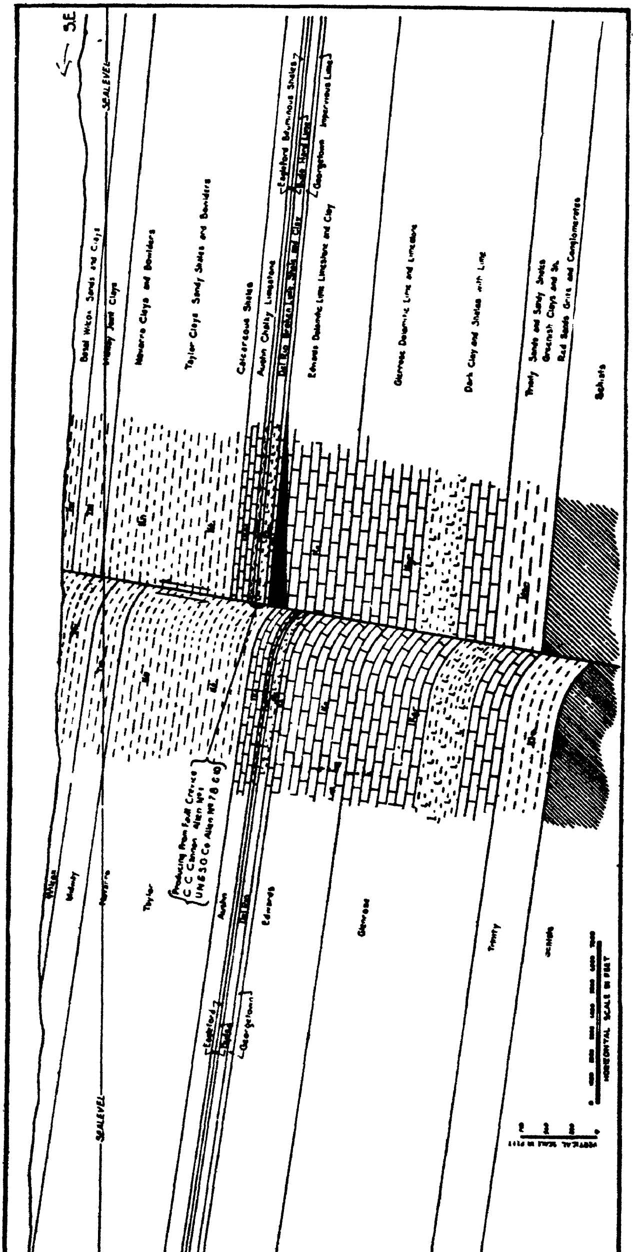

FIG. 146.—Generalized northwest-southeast cross-section showing structure and stratigraphy of the Luling fault. (*After Brucks, Bull. A.A.P.G.*, **9**, 638, Fig. 4.)

Eagle Ford, Buda, Del Rio, and Georgetown follow in regular succession, with a thickness and lithology not far different from the generalized section discussed in preceding pages. The structure is shown in Fig. 146, which is taken from Bruck's article.[1] Two features will be apparent immediately: First, the east dipping monocline, so characteristic of eastern Texas, has been faulted (with the downthrown block on the west side); secondly, contrary to what might be expected, the downthrown side is folded downward at the fault. The fault shown is one of a number of nearly parallel faults which have a trend of N. 35° E. The dip is variable from 48 to 65 degrees in a direction about N. 35° W. This makes a heave of from 1,000 to 1,800 feet on the top of the Edwards limestone. The amount of displacement varies from 450 to 500 feet within the limits of the field. On the northeast extremity and similarly in the southwest extremity there is either a cross-fault or a bend on direction of the fault, such that a closure of the structure is produced. The southeast side, of course, is closed by the normal dip of the monocline. The producing horizon in this field is the Edwards limestone which is found at a depth of from 1,590 to 1,720 feet below sea level. Contrary to expectations, perhaps, we find that the extremities are higher structurally than the center by about 40 feet. The dip of the producing horizon amounts to 200 to 275 feet per mile. The porosity of the limestone varies from 5 to 30 per cent and is not uniformly distributed, although it is always near the top of the formation. In most wells the greatest porosity is found from 15 to 30 feet below the top of the limestone. The great variation in pressure in the wells, and therefore of production, is attributed to differential porosity. The porosity persists below the oil horizon and may be as much as 150 feet thick, water being below the oil. At a depth of 250 feet a very cavernous condition in the limestone was noted in a few deep wells. As regards the origin of the oil Brucks suggests a number of possibilities. It may be indigenous to the Edwards limestone; it may have originated in the Eagle Ford and have migrated basinward from the northwest to the fault and then up the fault plane to the porous zone; or, finally, it may even have come from the southeast from the Eagle Fork shales. Salt water present in the producing horizon seems to be the same all over the field, indicating intercommunication of the porous zones. It is a

[1] See Bibliography.

saline water containing 5,000 to 6,000 parts per million of chlorine. It is highly charged with calcium bicarbonate and hydrogen sulphide. The oil has a gravity of from 26 to 29° Bé., yields 8 per cent naptha, 32 per cent gas oil, and 50 per cent light lubricating oil by ordinary topping methods. With high-pressure methods, 55 per cent gasoline is obtainable. The total production of the field, up to the end of 1929, amounted to nearly 45,000,000 barrels of oil and Brucks estimates that the total ultimate recovery will probably exceed 40,000,000.

Mexia Pool.—Perhaps the most sensational oil pool ever discovered is the Mexia pool located in northeastern Limestone County. The first well was drilled by the Humphreys Petroleum Company in November, 1920, on the advice of F. J. Fohs. A gas field had been located here years earlier in a shallow sand, but the first oil well produced from the deeper Woodbine sand. Development was slow the first year for various reasons, but in the latter part of 1921, a very intensive drilling campaign was started which put the production up to 153,000 barrels per day. During 1922, the daily production went as high as 300,000 barrels per day for a time and the total production for the year was over 30,000,000 barrels. The Midway rocks of Eocene age lie at the surface and are succeeded by Navarro, Taylor, Austin, Eagle Ford, and Woodbine formations of Cretaceous age. The sands and clays of the Midway, Navarro, and Taylor formations have a thickness of about 2,400 feet, the Austin chalk is 450 feet thick, and the Eagle Ford about 380 feet thick. The Woodbine sand at the base of the section is the producing horizon.

Figure 147 shows the structure of the Mexia field by means of a contour map and a cross-section (Fig. 142, p. 356). The cross-section brings out the fact that a fault has provided a trap for the oil in this instance. The reservoir sand in the Woodbine formation was found to be saturated only on the upthrown or eastern side of the fault. The anticlinal fold at the surface was known a long time before it was thought worthy of a deep test to the Woodbine horizon and its axis is shown in Fig. 147. The importance of the fault was not suspected when the first well was drilled to the deeper horizon. It will be noted that the fault plane changes its direction and amount of dip from one end to the other. Indeed, toward the south end the throw appears to be reversed, since the trace of the intersection of the fault plane with the basal Midway limestone crosses the trace of the intersection with the Woodbine

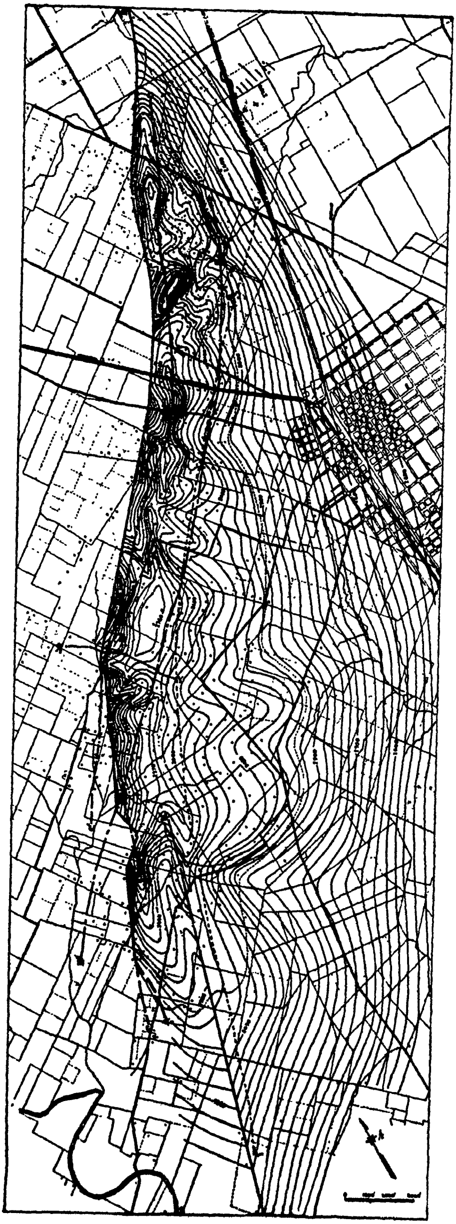

FIG. 147.—Subsurface structural map of the Mexia oil field. (*After Lahee, A.A.P.G. Symposium*, **1**, 334.)

sand near the southern end of production. This may, however, be explained by two faults as has been suggested by some geologists. The sand on the upthrow side is about 250 feet higher than on the downthrow side in the middle of the field, but this difference decreases rapidly toward the two ends of the field. Oil has accumulated in greatest quantity in the highest part of the arch against the central portion of the fault.

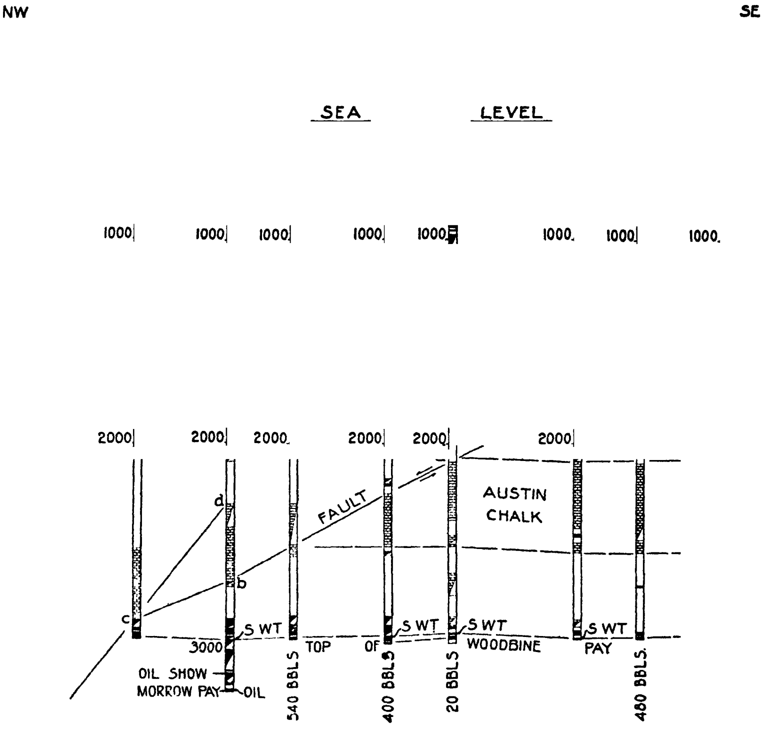

FIG. 148.—Cross-section based on logs in the Currie oil field, Navarro County, Texas. (*After Lahee*, A.A.P.G. *Symposium*, **1**, 342.)

The western edge of production coincides with the trace of the fault in the Woodbine sand. Complete drilling of the field indicated that the producing area is only 7 miles long and less than 1 mile wide. The gas area of the earlier Mexia gas field extended somewhat farther north and south, but it was also bounded sharply on the west by the fault indicating that in both cases the fault is the controlling element in trapping of the fluids. Figure 148 is taken from Lahee's article on the Currie field which

is similar to the Mexia field in all major features and lies but a few miles northeast of the Mexia field. It shows that the fault plane either changes its angle of dip markedly in the soft Eagle Ford shales or is completely absorbed in them and replaced by a new fault offsetting the first at some distance to the west. The total displacement in these faults amounts to nearly 400 feet.

Relation of Production to Structure.—From the typical examples of pools in the Balcones Fault district the reader will gain the impression that faulting is accountable for the trapping and accumulation of oil in this district. This seems to be true in practically every pool so far discovered in the district. Certain pools show some features which may make it necessary to modify the broad generalization somewhat. For instance, the early pools found at Corsicana and at Powell, have not been definitely proved to be associated with faults. Matson and Hopkins in their report on the Corsicana oil district reached the conclusion that the oil and gas occur under two different structural conditions. In some of the pools, as in the Burke pool, they occur along the crests of well-defined anticlines, in other pools, as at Corsicana, they occur on a monocline. Also they point out that the sands are very lenticular and that differential porosity and thickness of sand may be a very important factor in the occurrence of the oil and gas.

Again in the peculiar pools in which the oil reservoir consists of altered ingneous rock, as at Thrall and at Lytton Springs, the influence of faulting is not immediately apparent. Yet the diagram, Fig. 144, will show that some faulting has taken place after the igneous rock reached its final position and also that the fault lines are the lines of invasion of the igneous rock. Therefore, we must conclude that the faults have exercised a major control over accumulation of the oil and gas even here although the immediate reason for the occurrence of the oil is the porous condition of the serpentine. The serpentine has a domal surface which also may have had some influence in causing the oil to accumulate in it.

Production Statistics.—The pools of the Balcones Fault district have produced a really astonishing amount of oil in a relatively short time. Corsicana, the oldest, had produced to the end of 1929 a little over 6,000,000 barrels of oil. It produced from the shallow sands in the upper Cretaceous. The Woodbine production was larger as is indicated by the following figures:

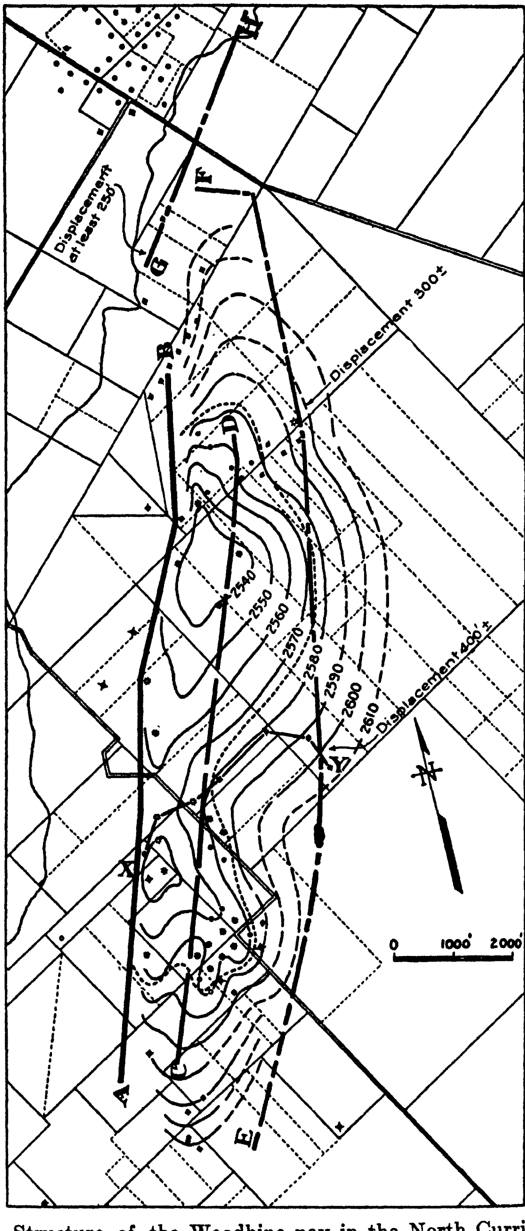

FIG. 149.—Structure of the Woodbine pay in the North Currie field. *EF*, fault in Midway lime; *CD*, trace of same fault in top of Austin Chalk; *AB*, trace of same fault in Woodbine "pay." (*After Lahee*, A.A.P.G. *Symposium*, **1**,

Up to the end of 1929, Mexia produced 83,000,000 barrels; Powell, 102,000,000 from the Woodbine and about 5,000,000 from the shallow sands; Currie about 5,000,000; Wortham, 21,000,000; and Richland, a little over 6,000,000. At the end of 1929, the daily average production in these pools was as follows: Mexia, 5,000; Wortham, 1,000; Currie, 400; Richland, 300; Powell, 7,000.

As a sample of the production from serpentine, Lytton Springs produced to the end of 1929 nearly 8,000,000 barrels of 38° gravity oil. The Edwards limestone production indicated by the Luling pool was well over 45,000,000 barrels up to the end of 1929. One of the most recent fields, the Nigger Creek pool, located some distance west of the main Mexia fault zone on an "inner" fault line, produced 3,000,000 barrels of oil from the middle of 1926 to the end of 1928. The per acre recovery up to the end of 1929 from the pools in the province was 30,000 barrels, and the total from all about 272,000,000 barrels.

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REYNOSA ESCARPMENT DISTRICT

If the Mexia Fault zone, represented by the Luling field in Guadelupe and Caldwell counties, is extended in the direction of its trend, a distance of about 90 miles across Wilson and Atascosa counties into Live Oak County, it connects with the Reynosa Fault zone. Up to date no oil or gas pools have been found in the intervening area, but it is unlikely that it will be found barren. Beginning in Live Oak County and extending through McMullen, Duvall, Webb, Jim Hogg, and Zapata counties, a number of oil and gas pools are found, all lying in a comparatively narrow strip of territory. They are closely related to the most prominent topographic feature of that part of Texas called the "Reynosa escarpment." This escarpment is 25 to 100 feet high in places and faces the west or northwest. Its top surface is covered with gravel, sand, and caliche making up the so-called "Reynosa formation." This material is resistant to erosion and has produced a cuesta called the "Reynosa escarpment." The early fields were all located along the western edge or zone of outliers of the escarpment and hence the district may be called the Reynosa Escarpment district.

The earliest pool to be discovered in the district is the Reiser gas field located in Webb County about 8 miles west of the escarpment. Five years later, the Jennings pool, also a gas pool, was discovered. It is located 20 miles south of the Reiser pool and in Zapata County, also some distance west of the escarpment. Neither of these pools aroused much interest in the district. In 1921, the first oil well was drilled in. It opened the Mirando Valley oil field located in the northeastern corner of Zapata County and exactly at the edge of the escarpment. Intense excitement prevailed as a result of this discovery, and during the same year further drilling along the escarpment served to uncover the Schott-Mirando City pool and the Carolina-Texas pool. During 1922, the Aviator's, the Leaseholders', and the Charco-Redondo pools were discovered, all lying either at the western edge of the escarpment or close to it. Since 1923, wildcatting in all directions has located other pools either connecting up the ones mentioned or entirely new ones east of the first group. One of these is the Jim Hogg pool in the northwest corner of Jim Hogg County discovered by Winne-Finch and Fariss in June, 1924. Another is the Cole-Bruni pool in southwestern Duval County discovered in 1926. Undoubtedly, this district is still in

its infancy and many more pools will be found, also much oil will probably be found at greater depth than at present.

Tectonics.—The controlling tectonic element in the district is a zone of faulting which may be called the Reynosa Fault zone.

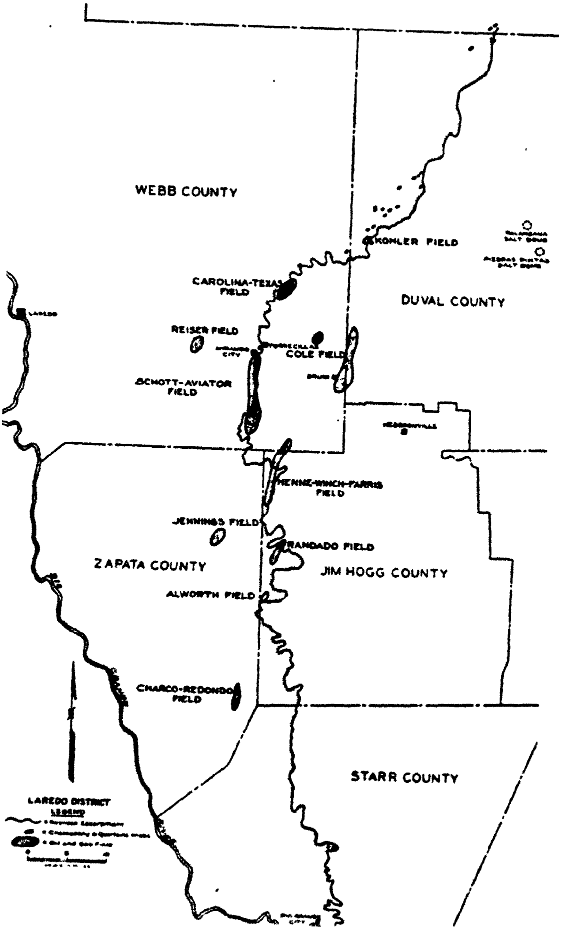

FIG. 150.—Oil and gas fields of Reynosa Escarpment district. (*After McFarland*, A.A.P.G., *Symposium*, 1, 394, Fig. 1.)

We lack the abundance of evidence for this fault zone which we have for the Mexia Fault zone. Most of the evidence is indirect in its nature. In one of the fields subsurface data have established a fault with a throw of 200 feet, but the evidence consists chiefly in the occurrence of opal and chalcedony. This siliceous

material occurs in the form of knobs or plugs which form prominent topographic features, and subordinately as vein filling and as cementing material. The knobs resemble volcanic plugs exposed by erosion and are so unusual in the region that they have received names such as Painted Rocks, Seven Sisters, Los Pichachos, etc. Many of the knobs line up along definite trends as if the material had come up in solution along lines of weakness and affected only the sandy layers along such lines. The chalcedony has in many places cemented the sands together to form hard quartzites. The westernmost outliers of the escarpment are made of such material and indicate that this is a line of very recent faulting. Figure 150 shows that all the fields located up to the end of 1928 are closely associated with the western edge of the escarpment. A study of the well logs shows that the dip of the strata is to the east and that there is practically no reverse dip to the west. This condition, coupled with the fact that production is bounded sharply on the west by an almost straight line, indicates that a fault or a series of en-echelon faults is present.

Stratigraphy.—The rocks exposed in the district and found in the subsurface zone (as far as it has been explored by the drill) consist entirely of Tertiary rocks. The series represented are the Eocene, Oligocene, and Miocene. The nomenclature,

TABLE OF FORMATIONS FOR THE REYNOSA DISTRICT

Series	Formation	Thickness, feet	Character
Pleistocene	Reynosa	175	Caliche, gravel, sand, conglomerate tuff, clay, and marl
Miocene	Oakville	200	Sands, grits, conglomerates
Oligocene	Gueydan	850	Tuffs and other volcanic rocks
Eocene	Frio	200	Shales, clays, a few sand layers
	*Fayette	850	Sand, sandy shale, volcanic material
	*Yegua	700	Shale, gumbo, some sands
	*Cook Mountain	1,000	Sands, shales (some black)
	Mt. Selman	700	Sands, shales, iron ore, and lignite
	Carrizo	150	Brown sandstone. Usually water
	Wilcox	700(?)	Shales, sands, lignite
	Midway	200(?)	Clays with basal limestone

thickness of each formation, and nature are best presented in a table.[1]

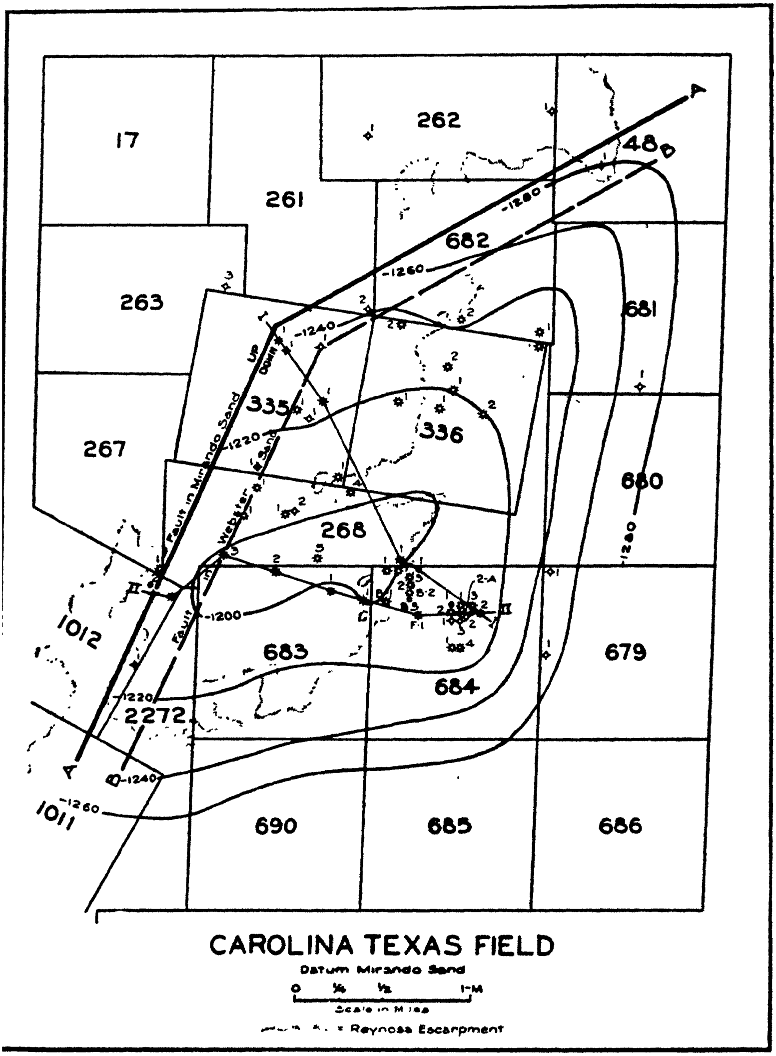

FIG. 151.—Structure of Carolina-Texas field as shown by contours on Mirando sand. (*After McFarland in* A.A.P.G. *Symposium*, 1.)

Because of the similarity in the lithologic character of the formations, it is difficult to pick the boundaries between them. The thicknesses given above are therefore approximate. The

[1] Based on paper by McFarland (see Bibliography).

formations which are starred are the ones which have the oil-bearing horizons.

Producing Horizons.—Up to date, production has been found in five different horizons in commercial quantities. Two sands are found in the Fayette; the *Cole* and the *Mirando.* The Cole sand has an average thickness of 25 feet and has been found to contain oil in the Randado pool as well as the Cole pool. The Mirando sand has been found productive over a wider area than any other sand. Because of shale and lignite "breaks" it is not oil bearing throughout its entire thickness of 50 feet. In the Yegua formation there is only one sand, the *Schott.* It lies 300 feet below the Mirando sand and is very lenticular. The Cook Mountain formation carries two sands, the *Webster* and the *Carolina-Texas.* The former lies about 500 feet below the Mirando, is approximately 30 feet thick, and is found in the Carolina-Texas as well as the Jennings pools. The lowest sand at present is the Carolina-Texas sand which produces only in the pool by the same name.

Relation of Production to Structure.—The principal factor in the accumulation of oil and gas in this district is the zone of faults on the west side of the area. McFarland believes that sands pinching out up the dip have also been instrumental in trapping oil. In Fig. 151, the Carolina-Texas pool is shown to be located on an anticlinal fold cut off on the west by a normal fault with a downthrow toward the east (200 feet displacement). Similar conditions obtain in the Aviator, Schott, and Henne-Winch-Fariss pools. The Randado pool and the oil in the Cole sand of the Cole pool are believed to fall into the category of pinching-sand accumulations.

The total production from the district up to June 30, 1929, has been somewhat more than 16,000,000 barrels of oil. Gas to the extent of about 40,000,000 cubic feet per day is taken out of the area.

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SABINE AND OUACHITA UPLIFTS DISTRICT

Another district which may be treated as a unit in the Gulf Embayment province includes northern Louisiana, southern Arkansas, and northeastern Texas. The scattered pools in this district are all related tectonically to two positive areas of the continental mass which have been named the *Sabine* and the *Ouachita uplifts.* Most of the important fields lie in northern Louisiana, but the fields of southern Arkansas have been discovered more recently and may in time assume nearly equal importance. The pools in northeastern Texas are very small and in nearly every case represent a portion of a pool located chiefly in the adjoining state. The counties involved in Texas are Marion, Harrison, and Panola. A portion of the Caddo field reaches over into Marion County; the Waskom gas field reaches over into Harrison County; and the Bethany gas field reaches over into Panola County. In northern Louisiana and southern Arkansas the following fields are included in this district:

On Sabine Uplift

Caddo, Louisiana Caddo parish
Pine Island, Caddo parish
Shreveport gas, Caddo parish
Sligo gas pool, Caddo parish
Elm Grove gas, Caddo parish
Waskom gas pool, Caddo parish
Bethany gas pool, Caddo parish
Bull Bayou, De Soto parish
Crichton, Red River parish
Pleasant Hill, Sabine parish
Spring Hill-Sarepta, Webster parish
Cotton Valley, Webster parish
Haynesville, Claiborne parish
Homer, Claiborne parish

On Ouachita Uplift

Richland gas pool, Richland parish
Monroe gas field, Ouachita, Union, Moorehouse parishes Arkansas
El Dorado, Union County
East El Dorado, Union County
Urbana gas pool, Union County
Champagnolle, Union County
Smackover light, Union County and Ouachita
Smackover heavy, Union County and Ouachita
Lisbon oil pool, Union County
Stephens oil pool, Columbia and Ouachita

On Angelina-Caldwell Flexure

Urania oil pool in La Salle parish

Figure 152 is a map of northern Louisiana and southern Arkansas which shows each of these fields and also indicates whether they are primarily oil- or gas-producing fields. In addition, the chief salines and salt domes are indicated, besides numerous oil and gas shows, also seepages.

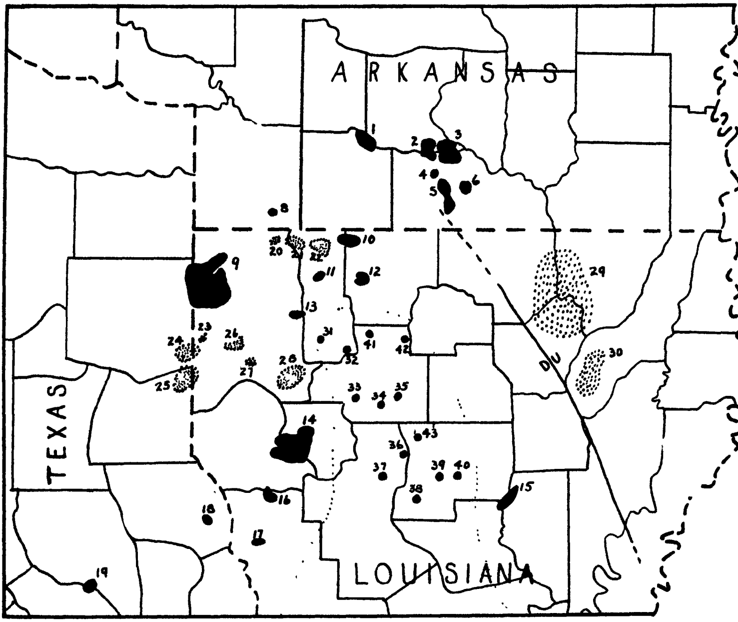

FIG. 152.—Index map of eastern Texas, northern Louisiana and southern Arkansas. (*After Easton, Oil and Gas Journal.*) Numbers 1 to 19 are oil pools, Nos. 20 to 30 gas pools, and Nos. 31 to 42 salt domes. (None of the salt domes have produced oil to date.)

1, Stevens; 2, Smackover light; 3, Smackover heavy; 4, Lisbon; 5, El Dorado; 6, East El Dorado; 7, Champagnolle; 8, Bradley; 9, Caddo; 10, Haynesville; 11, Cotton Valley; 12, Homer; 13, Bossier; 14, Crichton and Bull Bayou; 15, Urania; 16, Pleasant Hill; 17, Zwolle; 18, Pickering; 19, Nacagdoches; 20, Carterville; 21, Webster; 22, Springhill; 23, Shreveport; 24, Waskom; 25, Bethany; 26, Shreveport; 27, Sligo; 28, Elm Grove; 29, Monroe; 30, Richfield; 31, Bisteneau; 32, Vacherie; 33, King's salt dome; 34, Prothro; 35, Rayburn; 36, Drake's; 37, Clear Creek; 38, Coochie Brake; 39, Winnfield; 40, Cedar Creek; 41, Gibbsland; 42, Price's salt dome.

In this district oil and gas pools were located on the strength of gas seepages. Such seepages were known long before any wells were drilled, especially along the Red River in Caddo parish. In Ouachita parish nearly all water wells in the area now occupied by the Monroe field had gas in them and this finally led to drilling. The first well in the district was drilled in the Caddo

pool in Caddo parish in the year 1904. It was a gas well and did not arouse much interest in the region. Other wells were drilled in the same area, but it was not until about 1912 that real interest was shown in the district. About that time the rich oil reserves of De Soto and Red River parishes, the Bull Bayou and Crichton pools, were discovered. The final and most intensive search for oil was stimulated by the phenomenal performance of the Homer oil pool, which was brought in during the year 1919. The small but very prolific pools of Bellevue and Haynesville were located soon after. The large supply of gas in the Monroe field was found in 1906. In Arkansas, the search for oil was started very late as the region was looked upon with disfavor by geologists and operators alike. In 1920, a gas well was brought in by the Constantine Refining Company on a location recommended by a geologist. This well, strangely enough, failed to awaken much interest and it remained for a second well drilled about a year later to prove the possibilities of Arkansas as an oil-producing state.

Tectonic Elements.—Two major tectonic elements stand out in this district, the Sabine and the Ouachita uplifts. The former was first described by G. D. Harris when he was state geologist of Louisiana. It is a broad domal area approximately 80 miles in diameter located mainly in northwestern Louisiana, but affecting small portions of the two adjoining states. Figure 153 taken from Powers' article on the "Interior Domes" shows the location of the uplift, and, in a general way, its structural configuration by means of contours drawn at intervals of 500 feet. If a smaller contour interval had been used, the surface would appear to be minutely wrinkled and broken, for many small domes and anticlines are known to modify the broad domal outline of the uplift. Faults also are known at a number of points and probably many more are present whose existence has not been established by the drill. Two of these faults are, the one which cuts the De Soto-Red River fields and the other one the Homer. The former has a throw of 200 feet to the south and the latter a throw of 400 feet also down to the south. Both are shown on Fig. 154. This map also shows the Sabine uplift by means of contours which, in this case, are drawn on the Nacatoch sand or its equivalent. It reveals some of the smaller structural modifications as, for example, the Bellevue dome with 500 feet of closure (in eastern Bossier parish), the Homer faulted dome in

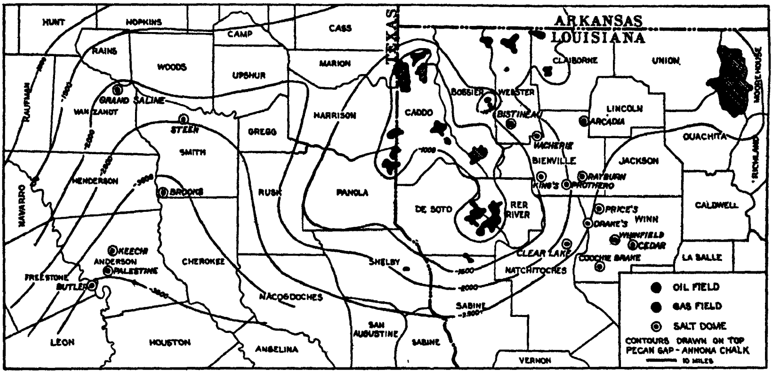

FIG. 153.—Subsurface structure contour map of eastern Texas and northern Louisiana contoured on the top of the Pecan Gap-Annona chalk. (*After Powers, Bull.* A.A.P.G., **10**, 5, Fig. 2.)

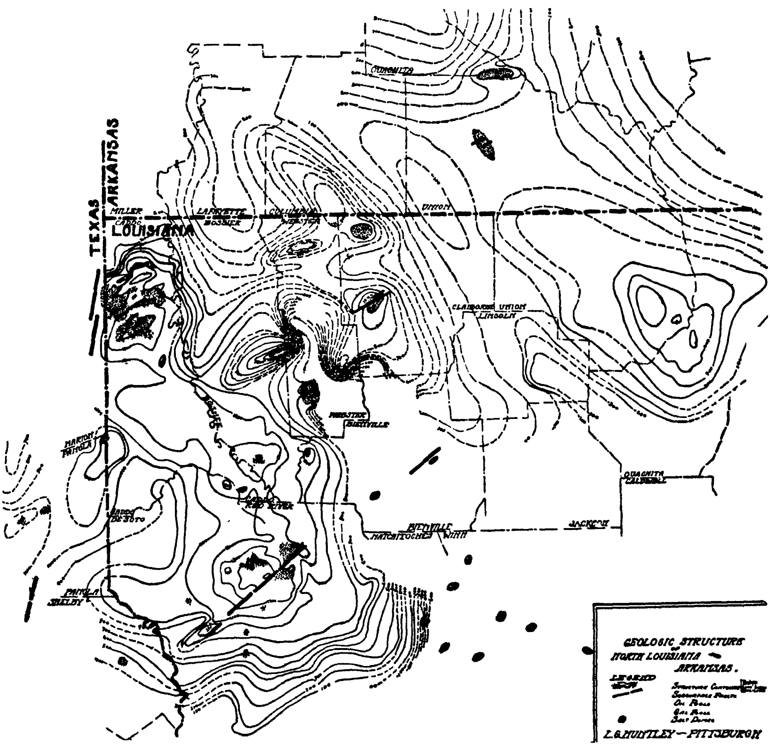

FIG. 154.—Geologic structure of northern Louisiana and southern Arkansas. (*After Huntley, Bull.* A.A.P.G., **7**, 180, Fig. 1.)

Claiborne parish with a structural relief of 1,200 feet, and the Spring Hill-Sarepta dome in northern Webster parish.

The regional dip in the district is toward the south and the southeast, but, on account of the Sabine uplift and the other structural features, the regional dip is very much obscured or interrupted. A line running from the outcrop of the Nacatoch sand, toward the southeast, drops about 2,370 feet in 57 miles (41 feet per mile) to the Louisiana state line, rises 300 feet in 8 miles to the top of the Haynesville structure, drops 100 feet in 10 miles between Haynesville and Homer, rises 1,000 feet in 5 miles to the top of the Homer dome and then drops 1,200 feet in the next 5 miles or at the rate of 240 feet per mile.

The Ouachita uplift is located in Richland, Ouachita, and Moorehouse parishes in Louisiana and extends northwest into Arkansas into Union, Calhoun, and Ouachita counties (see Figs. 152 and 154). It also is a very broad domal area on which are superposed smaller domes and anticlines and faults. It is located about 75 miles east of the Sabine uplift and somewhat lower structurally. Its outlines and minor configuration are not so well known because fewer wells have been drilled on it and around it. Between the Ouachita and Sabine uplifts is a synclinal tract which may represent a graben in the subsurface basement complex. Very little is known regarding this basement complex but very likely it consists of ancient crystalline rocks similar to those of the Piedmont plateau east of the Appalachian Mountains of which this part of the continent appears to be the geological continuation. When the foundering of the old land mass, Llanoria, took place, many faults were formed as is known from a study of the Balcones Fault district. It is entirely logical to assume that many faults with great displacement formed in the basement complex in this district. The downthrow in these was to the south, in general, leaving escarpments facing the south or southeast. It is probable that the Sabine uplift is located over one of these faulted segments of the earth's crust. The Ouachita uplift can be similarly placed over an escarpment facing the southwest. There is some subsurface evidence for a fault along the same line of weakness and this fault is shown on the map (Fig. 152) on page 379.

Stratigraphy.—The rocks which are involved in the district under consideration include the Comanchean, Cretaceous, and Tertiary systems with the usual surface deposits of recent and

Quaternary age. The names of the formations now used by geologists working in the district and the thickness of each is given in the following table:

GENERALIZED SECTION FOR SABINE-OUACHITA UPLIFTS DISTRICT

System		Formation	Thickness, feet	Character
Tertiary-Eocene		Jackson	500	Sands, clays, lignitic layers, volcanic ash
	Claiborne	Cockfield	400	Clays and sands, largely palustrine
		St. Maurice	150	Sandy clay containing shallow water marine shells
		Sparta sand	450	Unconsolidated sands with thin clays
		Cane River	250	Clays and sands, lignitiferous in part
		*Wilcox	200 2,000	Lignitiferous sands and clays with land plants
		Midway	400	Black calcareous clays with some limestone
Cretaceous	Navarro	Arkadelphia	100	Dark calcareous clays
		*Nacatoch sand	250	Indurated sand with thin calcareous layers, glauconitic in part
		Saratoga chalk	100	Clayey chalk with some greensand
		Marlbrook marl	125	Calcareous clay and clayey chalk
	Taylor	Annona chalk	200	White chalk
		Ozan	250	Blue calcareous clay
		*Buckrange sand	50	Sandy layers. *Blossom* sand
		Brownstown marl	150	Blue calcareous clay
		Tokio	300	Sands and gravel, with some clay
		Eagle Ford	50	Clay. Missing in many areas
		*Woodbine sand	100	Sands with thin clay partings
Comanchean		Washita and Fredericksburg	1,600	Shales and limestones. Some red
	Trinity	*Glen Rose	2,300	Limestones, shales, and sandstones
		Middle red	2,000	Red shale and sandstone
		Lower	500	Limestone and shale

The formations which crop out at the surface in this district all belong to the Tertiary or Quaternary systems with the exception of some small Cretaceous outcrops where salt domes have pushed up the older rocks in very small areas. These surface rocks are mostly unconsolidated clays, sands, and gravels and are very difficult to classify except on a paleontological basis.

This fact makes it apparent why geologists have had great difficulty in foretelling the location of the pools in the area. Nevertheless, some, like Haynesville and El Dorado, have been located by geologists. As a rule, however, the structure of the rocks at the surface is misleading rather than helpful on account of the local character of the dips and their inability to reflect subsurface conditions.

In the subsurface section geologists have received considerable help from several formations. The chief one of these formations is the Nacatoch sand. This name is applied to a series of sandy layers near the middle of the Navarro marl of Texas. They crop out at Nacatoch Bluff on the Little Missouri River, in Clark County, Arkansas, and they consist of sand layers interbedded with sandy limestone, and calcareous sandstone with a thickness of about 65 feet. This zone of sandy layers varies greatly from place to place both in thickness and in constitution, yet it is remarkably persistent as a zone and has been recognized in nearly every pool or field. It is the most important oil and gas horizon in the whole section.

Another important key horizon is the Annona chalk. This formation was named from the town of Annona in Red River County, Texas. It consists of white chalk and has a maximum thickness of 100 feet at White Cliffs in Arkansas where it is beautifully exposed. From there it seems to thin out in all directions and change to marls and marly clays. In the district where the oil occurs it is not pure chalk, but the chalky zone in which it appears is from 100 to 250 feet thick.

The Tokio formation, Eagle Ford clay, and Woodbine sand of the generalized section are sometimes called the "Bingen formation." This name was given by Veatch to a series of white or brown sands and clays containing some greensand and considerable lignite. Stephenson[1] believes that the Bingen should be divided into two divisions, and that the lower portion only is the equivalent of the Woodbine sand of Texas. The Tokio formation was named by Miser and Purdue in U. S. Geological Survey, *Bulletin* 690. It was set off from the rest of the Bingen because the upper part of the Bingen contains fossils which indicate post-Eagle Ford age. Sands, clays, gravels, and a basal conglomerate compose the formation. The Eagle Ford is entirely missing in southern Arkansas, but has been identified in some well cuttings on the south side of the Sabine uplift.

[1] See Bibliography.

Three important unconformities have been recognized in the general section, one at the base of the Comanchean, one at the base of the Cretaceous, and one at the base of the Tertiary system. The hiatus between the Comanchean and the Cretaceous is evidently a very long one, for in southwestern Arkansas the whole Washita and Fredericksburg series are eliminated and the Woodbine sand rests unconformably upon the Trinity series. The Trinity series crops out in southwestern Arkansas in a narrow belt. It is typically exposed near De Queen in Sevier County almost due north of Shreveport where it has a thickness of 600 feet. In the oil-fields area, the Trinity has been encountered in a number of places and found to be quite thick. It was found under the Caddo pool and some production is now obtained from the Glen Rose phase of the Trinity there. It was also found in the Cotton Valley pool and there also production is secured from the Glen Rose phase. Under the Monroe gas field in the eastern part of the district there are 200 feet of shales, thin sandstones, and argillaceous limestones which contain fossils of Comanchean age (probably Washita). Below these there are red shales in which also some fossils of Comanche age were found. On the outcrop of the Trinity in Arkansas and in the wells south of the outcrop the Trinity contains a good deal of red rock, so that these rocks may represent the Trinity.

Volcanic Rock.—One of the interesting phases of the stratigraphic record of this district is the frequent occurrence of volcanic rock. Perhaps the thickest deposit of this material (usually referred to as *bentonite*) is below the Monroe gas field, where it is locally 1,200 feet thick. At this locality the volcanic series consists of tuffs mostly, but there are also flow rocks or lavas at least in the lower several hundred feet. The lavas are highly altered and have a fine ground mass with large feldspar phenocrysts. The tuffs consist of some of the porphyritic flow rock and of vesicular and pumiceous material. Some of the fragments are so large that it locally becomes a volcanic breccia and indicates a nearby source. Typical bentonite has been found in Louisiana at a number of stratigraphic levels ranging in age from lower Cretaceous to the Jackson formation of Eocene age. It has been found on the outcrop at two places, one in the Jackson formation and the other in the St Maurice.[1] The bento-

[1] See Crider in Bibliography, *Bull.* A.A.P.G., **8**, 525.

nite from well cuttings exhibits characteristic properties which make it easily identifiable. It is a greenish-grey mud capable of slaking and swelling with the absorption of seven times its volume of water.

Producing Horizons.—The youngest producing horizon is one which has only recently been found productive. It is the *Wilcox* formation of Eocene age. This formation produces oil and gas in the Urania pool of La Salle Parish about 40 miles south of the Monroe gas field. The *Nacatoch* sand has been the most consistent and the largest producer of oil and gas in the district. It is found at a shallow depth of 300 feet in the Bellevue pool and as deep as 2,100 feet in some pools. Its maximum thickness is about 200 feet (the thickness in the Caddo field); at Homer, it is 100 feet thick; and at Bellevue, only about 78 feet thick. Many shale and lime partings are found in the total thickness and it is rarely a single body of sand. The actual producing portion is usually quite thin, or there may be several thin pay zones in a given well. The *Annona chalk* produces at two places. One of these is the very large gas field of Monroe which covers over 350 square miles and the other is in the Caddo pool. The chalk varies from 300 to 600 feet in thickness. At Monroe, the reservoir rock is 120 feet thick.

The *Blossom* sand is a rather important producing horizon which appears in the section about 800 feet below the Nacatoch sand and is often over 100 feet thick. It produces gas at Bethany, and oil at Homer, Haynesville, and Smackover. Stratigraphically it lies between the Brownstown marl and the Tokio formation and is considered to be a portion of the Austin chalk by Stephenson. Some geologists believe it is the same as the Buckrange sand, and it so correlated in the table on page 383.

In well logs, it is difficult to distinguish between the Blossom, Eagle Ford, and Woodbine, and these three are often referred to by Veatch's name of "Bingen." The Eagle Ford is believed to be missing in a large part of the district, but some production has been referred to it in the Caddo and De Soto fields. This production may, however, come from the Woodbine instead. The *Woodbine* used to be considered one of the most likely producing horizons in the district, but actual drilling has not proved this to be the case. It produces some gas at Bethany, Shreveport, and Elm Grove, and some of the oil at Caddo, Sligo, and Bull Bayou.

Perhaps the most interesting producing horizon, because of its future possibilities, is the *Glen Rose* formation. This was first found productive in the Pine Island pool of the Caddo field where it was called the Pine Island deep sand found at 2,900 feet. Later, 4 deeper horizons in the same formation were found at from 3,700 to 6,000 feet. The upper one of these horizons is a limestone and is associated with beds of massive anhydrite. The second is oolitic limestone, the third compact limestone, the fourth a true sand near the top of the red rock series, and the lowest, at 6,000, is a limestone. In the Cotton Valley field, the upper horizon in the Glen Rose is producing both gas and oil in commercial quantities. It is found at a depth of 4,400 feet in that pool. The Richland gas field (separated from the Monroe gas field by a low saddle) is producing gas from a Comanchean horizon, but it is not known exactly what formation is involved. Similarly, a well was recently brought in on the south side of the Sabine uplift in Sabine Parish which is also producing from a Comanchean horizon. In this case there is strong evidence that

TABLE OF PRODUCING HORIZONS IN THE SABINE-OUACHITA DISTRICT

System	Formation	Sand	Parish, county, or pool where productive
Tertiary	Wilcox	Wilcox	Urania pool in La Salle parish
Cretaceous	Nacatoch	Nacatoch	Gas at Gaddo, Shreveport, Waskom, Bethany, Sligo, Elm Grove, Bull Bayou, Bellevue, Homer, Sarepta, Cotton Valley, El Dorado, East El Dorado, Smackover. Oil at Homer, Bellevue, El Dorado, and Smackover
	Taylor and Tokio	Annona	Gas at Monroe, oil at Caddo
		Meakin, Graves	Oil and gas at Smackover
		Blossom	Gas at Bethany, Webster. Oil at Homer, Haynesville, Smackover, and Stephens
	Eagle Ford	Eagle Ford	Oil at Caddo and De Soto
	Woodbine	Woodbine	Gas at Shreveport and Elm Grove, oil and gas at Caddo, Bull Bayou, Sligo
Comanchean	Washita	(?)	Sabine Parish
	Trinity	Glen Rose	Oil and gas at Cotton Valley in upper part and at Pine Island in upper and lower part of formation

the producing horizon is of Washita age. For purposes of reference the producing horizons and the pools where they produce are summarized in the table on page 387.

Typical Fields.—It is not easy to choose a typical field in this district because each one presents certain peculiarities. Some are large, some of medium size, and some very small. There is a great variation in structural conditions also. Perhaps the two most representative ones are the Caddo and the Homer pools. These will be described briefly.

The *Caddo field* is located in Caddo County in the northwestern part of Louisiana. It consists of a number of pools all of which cover an area of about 180 square miles. Gas seepages led to the first test and no surface geological information is available to indicate the surface structure. The first successful well was drilled in 1906. The field is located high on the Sabine uplift, but within the field there is a structural relief of only 200 feet. A number of small domes and anticlines have been mapped on the uppermost producing horizon which seems to control production to a large extent. The Nacatoch sand produces gas only and from a depth of 800 to 1,000 feet. The Blossom sand produces a very small amount of oil. The so-called Woodbine found at a depth of from 2,200 to 2,275 feet is the source of most of the high-grade oil found in the field. It appears to be partly basal sand lenses in the Cretaceous, and partly sand layers in the Comanche, which lies unconformably below it. For this reason the relation between the structure and production is the not very close. Below Cretaceous, there are five other horizons which may produce oil and gas in large amounts. They are in the Trinity formation of the Comanchean system. The gravity of the oil is about 38° Bé., and the production of the field up to the end of 1929 has been 124,000,000 barrels. The *Homer pool* is located in Claiborne parish, 45 miles northeast of Shreveport. It differs fom most of the other pools by having a topographic high above a structural high. Structurally, it is an isolated dome of small dimensions (5 square miles) located on the eastern side of the Sabine uplift. The relief measured on the Nacatoch sand amounts to over 1,200 feet. A fault trending nearly east to west cuts the producing area into two parts. This fault has a throw of 400 feet toward the south. Wilcox and Claiborne rocks crop out on the surface and the subsurface section is similar to the one given in the generalized section on page 383.

The Nacatoch sand produces some of the oil and the Blossom sand which lies 700 feet lower produces the rest, the oil from both being the same gravity. Some of the wells in the Homer pool were phenomenally large for high-gravity oil, 10,000-barrel wells being frequent and some as large as 18,000 were reported.

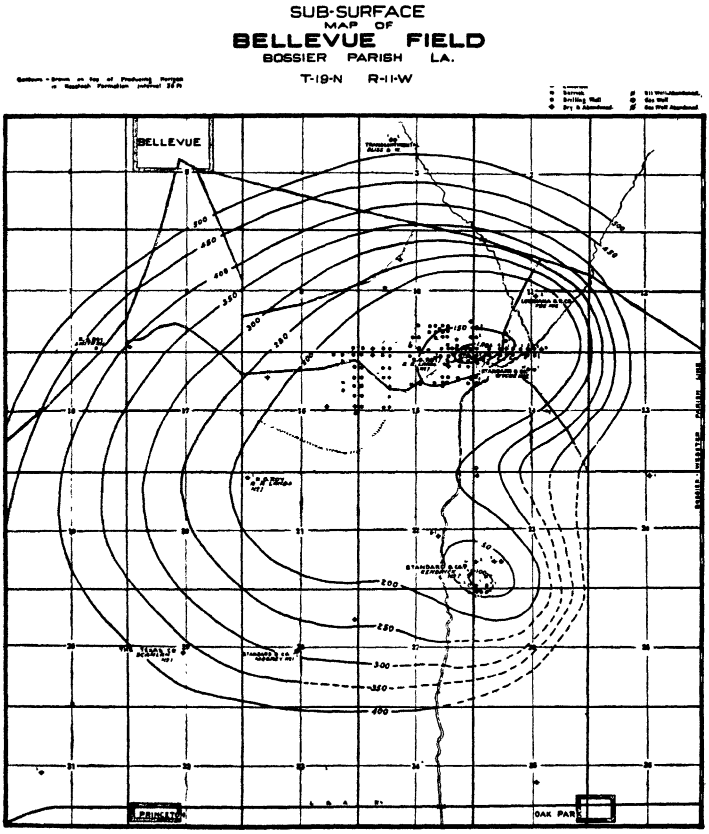

FIG. 155.—Subsurface map of Bellevue field. (*Holman and Campbell, Bull. A.A.P.G.*, **7**, 646, Fig. 1.)

The field was opened in 1920 and by the end of the next year the production had reached over 21,000,000 barrels, due to the gusher wells. By the end of 1929 this small pool had produced nearly 58,000,000 barrels of oil.

The *Bellevue pool* is a remarkable pool in many ways, and deserves a few remarks. It is one of the few pools which were located by surface geology. Veatch had pointed out the fact

that a structure existed here as early as 1905, but it was not tested until 1917. A dry hole resulted. Two years later, another test was made with better results, some production being obtained from the Woodbine at 2,173 feet. Claiborne rocks are exposed on the surface followed by Arkadelphia, Nacatoch, etc., down to the Trinity formation. The structure of the Nacatoch sand shows a dome with 830 feet closure superposed on the east side of the Sabine uplift (see Fig. 154 p. 381). The best production was finally obtained from an area of only 1 square mile and from the Nacatoch sand at the remarkably shallow depth of about 300 feet. A few wells were obtained in the Woodbine sand and one gas well was secured in the Trinity formation. The total production of oil up to the end of 1929 amounts to about 8,000,000 barrels.

Another unusual field is the *Monroe gas field*. It is located in Ouachita, Union, and Moorehouse parishes in the eastern part of the district. Its size is immense, for it covers over 350 square miles of proved territory. The first well was drilled in 1906 and at present there are nearly 100 wells producing. The surface rocks belong to the Wilcox formation of Eocene age, below which the Arkadelphia clay, Marlbrook, and Annona chalk are found. The Annona chalk is 120 feet thick and is the *producing gas horizon*. A lower gas pay of lesser importance is found about 200 to 400 feet below the Annona and is thought to be in the Eagle Ford. The formations below the Annona are not yet well known because few wells have penetrated them. There is some indication that the Annona is succeeded by 1,200 feet of volcanic ash below which the Comanchean rocks appear. The volcanic ash has not been found to extend horizontally, as was expected, and our knowledge of subsurface conditions is therefore still somewhat obscure. The porosity of the Annona chalk is greatest along the crest of the dome and least on the sides, but is apparently fairly uniform throughout. The producing area has a structural relief of about 300 feet and the large dome is modified by several small domes which have a relief of about 100 feet. These smaller domes trend southwest to northeast and may be located above faults in the more rigid rocks below. By the end of 1929, this field had produced over 125,000,000 cubic feet of gas and it was estimated that its ultimate total production would be in excess of 1,710,000,000,000 cubic feet.[1]

[1] STROUD and SHAYES (see Bibliography).

FIELDS LOCATED IN ARKANSAS

The fields of the Sabine-Ouachita Uplift district which lie in Arkansas are shown on the map (Fig. 152). The oldest of these is the El Dorado field discovered in 1920 and located in Union County. Farther north, on the border line between Ouachita and Union counties, lies the Smackover field discovered in 1922. It is divided into two parts, one part producing heavy crude and the other rather light crude and for that reason the parts are referred to as the Smackover light and the Smackover heavy pools. An important extension of this field is the Norphlet pool. The Stephens oil field was located toward the northwest by wildcatting. It is located at the intersection of Ouachita and Columbia counties. In south-central Nevada County there is a small oil field called the Irma pool (Fig. 156). The most recent pool to be discovered is the Champagnolle pool in eastern Union County.

The *El Dorado* pool covers an area of 12,000 acres or more and is peculiar in a number of respects, but fairly typical of all the pools in southern Arkansas. The sur-

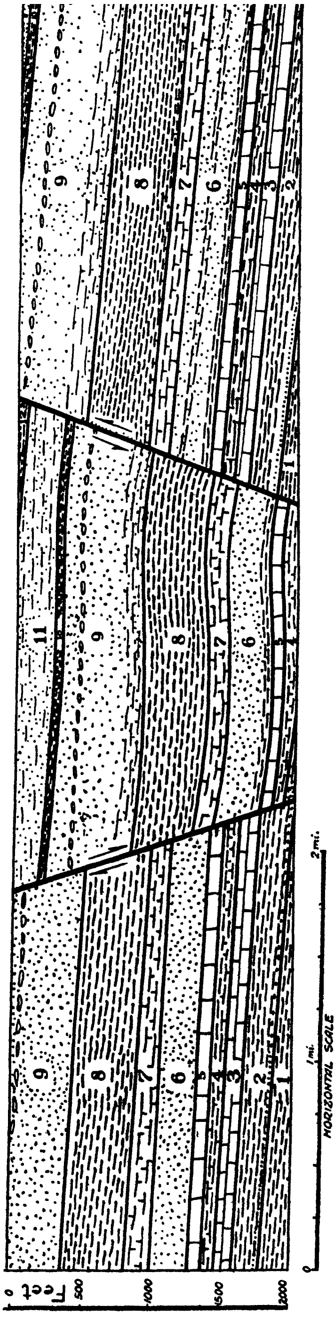

FIG. 156.—Geologic cross-section through the Irma field. 1, Brownstone marl; 2, Ozan formation with Buckrange sand at base; 3 Annona chalk, 4, Marlbrook marl; 5, Saratoga chalk; 6, Nacatoch sand; 7, Arkadelphia marl; 8, Midway; 9, Wilcox; 10, Cane River; 11 Queen City; 12, Mount Selman. (*After Teas, A.A.P.G. Symposium*, 1, 9.)

face topography is similar to the Louisiana pools in that it is relatively flat and non-committal as regards structure. On the surface, Claiborne strata are exposed under a thin veneer of Quaternary deposits. Below the Claiborne, the normal succession of Wilcox and Midway, Arkadelphia clay is found down to the Nacatoch sand at 2,150 feet. The surface dips are not usable for deciphering structure and are very misleading, in fact. On the Nacatoch formation the structure is found to be anticlinal modified by a fault on the northeast side of the pool. This anticline is one of a great many minor structural features superposed upon the Ouachita uplift which extends from the Monroe gas field in Louisiana toward the northwest into Arkansas. The anticline is about 7 miles long and 3 miles wide with a number of small domes on it, one of which has a closure of nearly 35 feet. There are two producing horizons. The upper one is the most important at present and is correlated with the Nacatoch sand of the Cretaceous section. It is very erratic in thickness and porosity, consisting of a series of sandy, lenses separated by shale partings. Any of the sand lenses may produce oil, but the best production is usually found 40 feet below the top of the Nacatoch (total thickness about 180 feet). This is the second pay streak of the upper three. In each pay zone or streak there is also water, so that great care must be, exercised to drill only a few feet into the producing sand. Despite these precautions, practically every well makes salt water with the oil or gas. True to the anticlinal theory of accumulation, the gas seems to occur only on the highest parts of the anticline and the oil occurs for the most part on the east and south flank. The fault which bounds the field on the northeast side may have been influential in guiding the migration of the fluids found in the wells. It has only a small displacement and the downthrow is on the east side. The gravity of the oil is another unusual feature, for it differs from well to well. The total range in gravity is from 29 to 39° Bé. A second sand has been found productive in a few wells. It lies about 400 feet below the top of the Nacatoch. This sand will no doubt be tested further when the upper sand reaches a state of exhaustion.

The *Smackover field* in Union and Ouachita counties is very similar to the El Dorado field. It seems to be located on an anticlinal nose which has a fault on the north side running nearly east and west. In this field four sands have been differentiated:

namely, the Nacatoch, found at 1,925 to 2,150 feet; the Meakin, found at 2,230 to 2,360 feet; the Graves, found at 2,340 to 2,500 feet; and the Blossom sand found at 2,550 to 2,660 feet. The Nacatoch sand is a series of sandy lenses, shales, and sandy limestones with a thickness of 165 feet. Within this formation the sandy lenses average about 25 feet thick and a number of them are productive. Taken as a whole, the Nacatoch is productive over the whole field and is one of the two large producers. The largest well had an initial production of 25,000 barrels per day. The gravity of the oil averages 20° Bé. The second or Meakin sand has an average thickness of 55 feet. It produces oil or gas in the northwestern part of the field and only dry gas in the eastern part of the field. The wells average 200 barrels initial production and the gravity is about 25° Bé. The third sand, or the Graves, has an average thickness of 35 feet and is the second in importance. The average initial production of the wells in this sand is 2,000 barrels, although some wells with an initial production of from 15,000 to 70,000 barrels were completed in it. The gravity is 21° Bé. and the sand is productive only in the eastern part of the field. The fourth, or Blossom sand, has an average thickness of 20 feet. The wells from this sand have an initial production of from 300 to 3,000 barrels of 24° Bé. gravity oil. The gas wells average about 40,000,000 cubic feet per day with a pressure of 1,100 pounds to the square inch.

Relation of Production to Structure.—In the Sabine-Ouachita uplifts district there is a striking relation between production and structure. Not only have the major tectonic elements controlled the migration and accumulation of oil and gas, but many of the minor structural elements have served to trap these fluids. Both faults and folds have trapped oil and gas. If all the subsurface information desired about this district were available, it would probably be found that deep-seated faults are very common, and the important avenues of upward migration of oil would be discovered. It might prove that some of the faults that have been discovered in drilling, such as the one at Homer and the one in the De Soto-Red River field, are faults which trend parallel to the deep-seated faults. Also some other faults might be found, as perhaps those of the El Dorado, Smackover, and Stephens fields in Arkansas, which make an angle with the deep-seated faults according to the principle first enunciated by Fath and described in preceding pages in connection with faults in eastern

Oklahoma. Many folds in this district are no doubt the surface reflection of a deeper fault because the higher formations so commonly consist of soft, more or less unconsolidated sediments incapable of preserving a fault.

It has been stated that in the Caddo field small domes and anticlines contain most of the oil and gas. The same is true in the De Soto-Red River field. In Bellevue, there is a small but very high dome holding all the oil. In Homer, there is a faulted dome of great relief and in Haynesville, a similar dome, but with much smaller relief. In the Bethany gas field, which extends partly into Texas, there is an anticline with two domes on it separated by a fault. At Cotton Valley, a small dome contains the oil. At Monroe, there is a very large dome with smaller domes superposed upon it which contains gas over an area more than 350 miles square. The same remarks might be made with reference to the lesser pools and fields of the district. In brief, then, the relation between production and structure in this district is very close and some perfect examples of the anticlinal theory of oil occurrence, such as Bellevue or Cotton Valley, might be shown.

The source of the oil and gas in this district is not known, but some geologists believe that it has a very deep source, namely, the Paleozoic sediments which may underlie the Comanchean. One reason for this belief is the occurrence of so many asphalt deposits along the outcrop of the Trinity formation in southern Arkansas.[1] Other geologists believe that the oil and gas have their source at many different stratigraphic horizons in the section and that they have not migrated far from their original position.

Production Statistics.—Northern Louisiana and southern Arkansas have produced a prodigious amount of oil and gas. The largest production from any individual field is from the Caddo field which produced practically 124,000,000 barrels from 1906 to the end of 1929. Haynesville and Homer, considering their small area, produced a remarkable total. From 1919 to 1929, Homer produced about 58,000,000 and Haynesville, 53,000,000 barrels of oil. Bellevue, which has an area of only 1 square mile, produced to the end of 1927 the total of 7,653,000 barrels. Urania, the most recent field with one exception, and which produces from the Tertiary rocks, yielded over 6,000,000 barrels in 2 years. All the fields in northern Louisiana produced

[1] Miser (see Bibliography).

up to the end of 1929 a total of 310,000,000 barrels of oil. Arkansas, from 1921 to 1929, produced a total of 320,000,000 barrels of oil. It reached a peak in 1925 when nearly 79,000,000 barrels were taken out of the ground. Smackover accounted for 74,000,000 of this total for 1925.

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THE SALT-DOME DISTRICT

In Louisiana and Texas there are some very small oil and gas fields which are roughly circular in area and associated with quaquaversal structural conditions. The area covered by these fields is rarely greater than 4 square miles and usually much less. The amount of oil taken from some of them is quite phenomenal, however, and exceeds the per-acre production of any other district in the United States, if not in the world. In one field, the production runs as high as 300,000 barrels per acre and in another one close to 200,000 barrels per acre.

The credit for discovering such fields and first proving the combination of conditions under which they occur belongs to Captain Lucas, an engineer with vision and perseverance. He had noted in his travels, in the coastal region of the Gulf states, that gas seepages, sulphur-water springs, and salt salines were associated and rightly presumed that petroleum might be found at depth. By a good stroke of fortune he decided to try out the practical value of his theories at Spindletop, near the town of Beaumont, in southeastern Texas. The escape of gas from two points (known as Copperas pond and the mud springs) had led to some drilling before Lucas arrived, but no oil had been obtained. His first well, drilled in 1900 to a depth of 575 feet, was lost, but enough oil was found to prove the existence of the elusive substance. In 1901, he tried again, and this time found production at a depth of 1,139 feet. The gas pressure encountered at this depth was so enormous that it threw a 6-inch stream of oil over 200 feet into the air. No preparation for such a gusher had been made, of course, and the oil amounting to an estimated quantity of 75,000 barrels per day was allowed to run off. After flowing a few days the well caught fire and when it was finally brought under control the casing was found to have collapsed.

The details of this world's record gusher spread around like wildfire and before very long every oil operator was looking for a dome like Spindletop, which had gas seepages and similar surface indications of oil. Many such domes were immediately located, as for instance, Barber's Hill, Big Hill in Matagorda County, and Big Hill in Jefferson County, Bryan Heights, Damon Mound, etc. Also many places were found where there is no surface mound, but where gas seepages or mineralized water springs were known. Twenty or more of these were tested during the same year that Spindletop blew in so forcefully. Many dry holes resulted and a great many disappointments were scored; nevertheless, where perseverance was practised, a field was often brought in after many failures. Some domes did not begin to produce until 10 to 20 years later. One of the first results obtained from the early drilling was the discovery that nearly all of the domes have a cylindrical plug of salt as a core. This plug of nearly pure salt was found at varying depths of from 15 to below 2,000 feet. Above the salt, drillers found another unusual rock series for the Gulf coastal region, namely, limestone, gypsum, and anhydrite, the "cap rock" for the salt plug. Some-

times only anhydrite is present, but usually there is gypsum above it and in most cases the limestone rests on the gypsum.

Careful geologic work in Texas and especially Louisiana by such men as Harris and Veatch, in the early days, and more recently by Rogers, Barton, and others, has given a wealth of

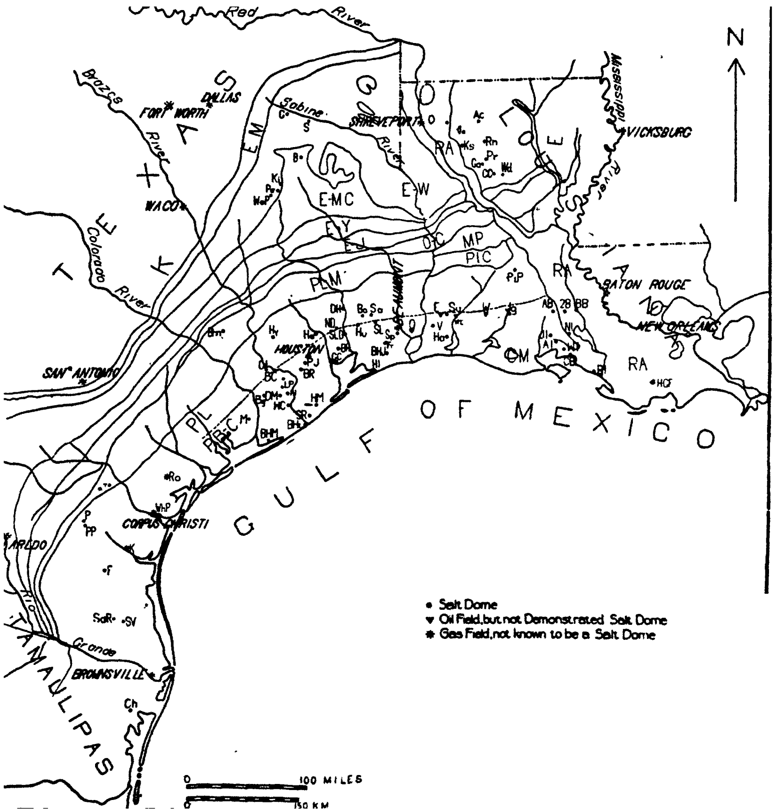

FIG. 157.—Sketch geologic map of Texas and Louisiana showing the location of the salt domes. (*After Barton, Bull.* A.A.P.G., 9, Pl. XXVI, opp. p. 1231.)

detail regarding these peculiar structures such as is not available for any other group of oil fields. Even now, some problems regarding them are not to be considered as settled. The origin of the salt plugs and the origin of the cap rock are still debated. The most vexing problem perhaps is to explain the force which caused the salt plugs to assume their present position. Figure 157 will show the location of most of the salt domes discovered

up to 1924. During the last few years, quite a number of new domes have been located by means of the seismograph and the torsion balance. On the map, about 75 domes and suspected domes are charted. They may be divided into three groups according to their location: The first group is located along the present shore line and within 150 miles of the coast. This is the coastal group. The second group is located in northwestern Louisiana (see Fig. 157), in the syncline between the Sabine and the Ouachita uplifts, or, more exactly, on the east flank of the Sabine uplift. They are the *interior domes* of Louisiana. The third group is located in northeastern Texas in the syncline between the Sabine uplift and the Mexia Fault zone (see Figs. 139 and 157). They are usually referred to as the *interior domes* of Texas. Most of our attention will be devoted to the first group, because the other two groups, with one exception, have not produced oil or gas in commercial quantities up to date. The interior domes are chiefly of interest because they throw a great deal of light upon the origin of the domes and associated phenomena.

Not all the coastal domes have been found productive of oil and gas, in fact the great majority have not produced a drop of oil. In some of them the contained salt is mined and furnishes as much revenue as the oil might have done. In a few, sulphur has formed in the cap rock, by alteration of the cap-rock materials, and this has furnished the nucleus for a very important industry in the South. Lastly, the limestone of the cap rock has also been found of considerable importance in a part of our country where limestone is comparatively rare. This material, of course, is used only where the cap rock protrudes from the ground, whereas the salt and sulphur are mined underground.

Topography.—The topography and other surface indications of the salt domes are very characteristic, although only a few of them are present on the same dome. One very striking feature is the domal arching of the surface beds above a salt plug. This doming is observed in the Gulf Coastal country, because it is in such striking contrast to the normal flat, featureless nature of the surface. Many of the domes have the surface so gently arched that the eye cannot detect the uplift, but gravity has detected it. In such cases, the sudden bend in a stream's course is often suggestive. Sometimes a central hill appears which is surrounded by a circular drainage system. Spindletop, Big Hill,

High Hill, Barber's Hill, Damon Mound, Hoskins' Mound, and Bryan Heights are all names which suggest an elevation prominent enough to have impressed the natives. The highest of these is Damon Mound which rises about 83 feet above the level of the surrounding prairie. Barber's Hill is 45 feet high and the others rise to lesser heights. In Louisiana, there are some higher mounds, as for example Avery Island, one of the famous Five Islands. It is 152 feet high, above the level of the sea marshes which surround it.

On some of the domes, solution of the salt mass at shallow depth has produced a central depression or basin surrounded by low hills. Anse la Butte, Jefferson Island, and Pine Prairie in Louisiana have such central depressions. In all of these the salt lies within 200 feet of the surface. In the Jennings dome there is also a central depression, but no salt has been found beneath it and therefore this depression may have a different origin.

Surface Indications of Oil.—On many of the domes gas has been known to escape for years. Barber's Hill, Goose Creek, Edgerly, Jennings, Bayou Bouillon, and Welch are among the prominent domes which were located because of such seepages. In some of these the gas escaped through water and aroused attention by bubbling. Paraffin dirt, or clay impregnated with sulphur, has been found on a number of the domes and this soon became known to prospectors as a favorable indication of a salt core beneath. Actual petroleum seepages have also been reported from some domes. Such was the case in the early days of the Sulphur dome in Calcasieu Parish in Louisiana, but, strangely enough, no oil in commercial quantities was ever found on this particular dome. Perhaps the most interesting substance which sometimes indicates a salt dome is the so-called "sour dirt." This material is bluish black in color but weathers yellowish on exposure. It is siliceous material saturated with soluble sulphates and chlorides of iron, aluminum, magnesium, and calcium. It possesses a sour, acid taste and is always moist. Indians were well acquainted with a deposit of this material on Damon Mound, as attested by the finding of arrowheads, etc. They used it as a medicine, and at present the Vitalitas Company prepares it for market as a medicine.

The Salt Plug.—The great amount of test drilling which has been done on the salt domes since 1901 has given abundant

information regarding the nature, dimensions, thickness, and surface configuration of the salt plug. It appears to be a very nearly cylindrical mass with very steeply dipping, almost vertical sides. The top is uniformly found to be strikingly flat. No well has ever passed through the salt in any dome, although some wells have been drilled as much as 4,000 feet into it. Therefore, it is known that it must be a very tall cylinder. In ground plan, the salt mass is nearly circular and, as to size, it rarely exceeds 4 miles in diameter. Most domes average about 2 by 1½ miles in diameter. Hockley, one of the largest, measures 4 by 2 miles and Sulphur dome, which is probably the smallest, measures only 75 acres across the top of the dome. The salt may come to the surface or it may be so deep down beneath the surface that a well 5,000 feet deep has failed to reach it. Avery Dome, one of the Five Islands of Louisiana, has the shallowest salt mass. It lies only 17 feet below the surface and actually lies above sea level. Avery Island has a very irregular surface topography and this no doubt is due to the solution of the salt, because drilling has shown the top of the salt to be very uneven, which is not the case as a rule in other domes. At Damon Mound the salt comes to within 375 feet of the surface. In contrast to these figures, we may cite Goose Creek, in Texas, and Edgerly, Jennings and Welch, in Louisiana, as domes with all the characteristics of a true salt dome, but without salt. At Goose Creek, wells over 5,000 feet deep have not found the salt nor the cap rock above the salt. At Welch and Jennings, the cap rock has been found, but not the salt. At Edgerly, a deep test to the depth of 5,425 feet failed to locate the salt or the cap rock.

The most complete data regarding the salt have been furnished by the salt mines of the Five Islands, notably the Avery dome. In this dome, the salt is a remarkably pure sodium-chloride deposit. It resembles a schist as Fig. 158 shows. The banded appearance in the salt is due to the presence of minute particles of transparent anhydrite which (because of the absorption of light) produce the dark bands in the salt. The bands are arranged in perfect parallelism in vertical section as Fig. 158 shows. Also, they are arranged with nicely adjusted parallelism to the periphery of the dome. In ground plan they look very different. Figure 159 shows that the dark bands are twisted and warped in a most intricate manner, as well as being more or less discontinuous. These features indicate that the salt has

been subjected to pressure from below and pushed up into its present position. The only foreign material in the salt at Avery

FIG. 158.—Flow structure in the salt, Avery Island, La. (*After Rogers, Bull.* A.A.P.G., **9**, 767, Fig. 4.)

Island is a mass of red sandstone 80 feet long and 75 feet wide and very thin in cross-section. It is made up of quartz and

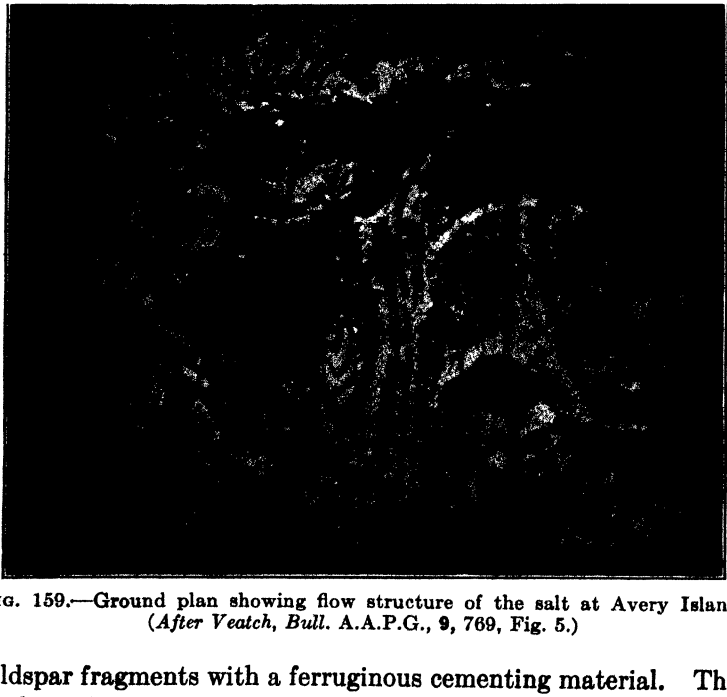

FIG. 159.—Ground plan showing flow structure of the salt at Avery Island. (*After Veatch, Bull.* A.A.P.G., **9**, 769, Fig. 5.)

feldspar fragments with a ferruginous cementing material. This is the only case on record of clastic rock imbedded in the salt

core. It is of great significance with regard to the original position of the salt.

The Cap Rock.—Directly above the salt mass there is usually a disc-like mass of anhydrite. Sometimes it reaches to the edge of the salt only and sometimes it extends down the sides of the salt a short distance. Figure 160, taken from Barton's article on the salt domes of South Texas, shows the variations which have been found in the cap rock on American salt domes. Sections are all natural scale, (*A*) Palangana; (*B*) Bryan

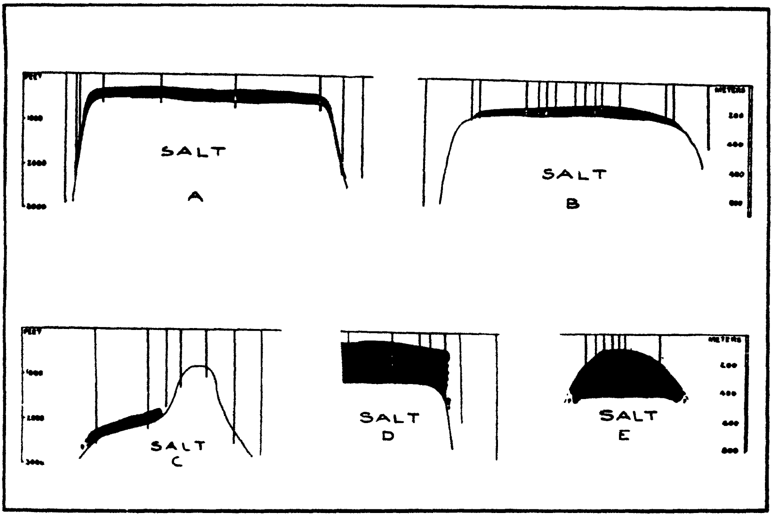

FIG. 160.—Types of cap in the American salt domes. (*After Barton, Bull. A.A.P.G.*, **9**, 569, Fig. 7.)

Heights; (*C*) New Iberia; (*D*) east side of Hockley; (*E*) sulphur. The anhydrite consists of uniform, even-grained, homogeneous, anhydrite or selenite. Sometimes, the upper portion of the anhydrite has been altered to gypsum by hydration, in which case there is usually also a third member of the cap. This third and upper member consists of limestone, or calcite, as Goldman prefers to call it. He believes that the calcite cap is a product of replacement by calcite of the sedimentary beds adjacent to the cap. Both calcite and the sulphur, which is sometimes found between the calcite and the anhydrite, probably resulted from the reduction of the outer parts of the cap by hydrocarbons from adjacent beds.

In some domes, the cap rock is exposed at the surface and may be conveniently studied. This is true at Damon Mound in Texas, and at Pine Prairie and the Five Islands in Louisiana. At Belle Island, which is one of the Five Islands, the cap rock is made up of the same material as the impurities in the associated salt mass. This seems to indicate that the cap rock is due to solution of the salt and consists of the residue left after solution, a statement which applies most forcibly to the anhydrite, for, as was seen in the case of the Avery dome, the salt is full of thin

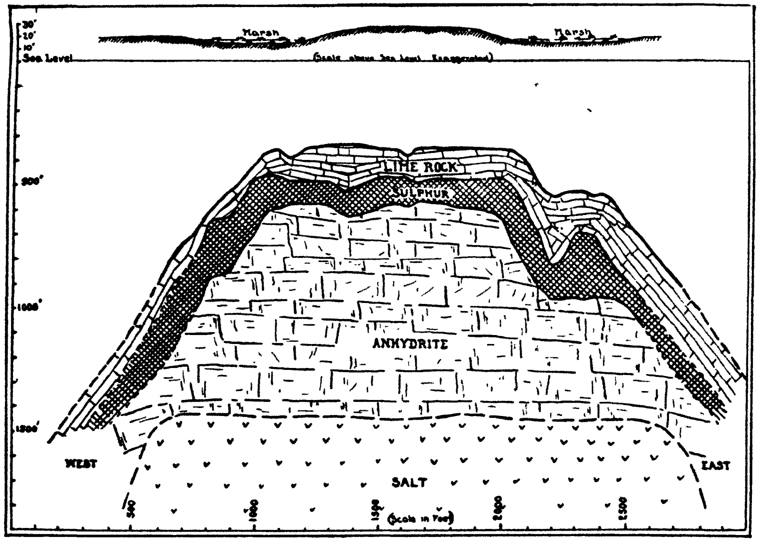

FIG. 161.—Sulphur salt dome, east to west section. (*After Kelley, Bull.* A.A.P.G., **9**, 485, Fig. 6.)

bands of finely divided anhydrite. The sulphur, gypsum, and limestone are, no doubt, secondary.

At Pine Prairie, the limestone portion of the cap rock is exposed. It is a thimble-like mass, which, with the anhydrite underneath, fits over the salt. On the top of the dome it is 200 to 400 feet thick, but at the edges some wells have penetrated over 1,000 feet of the steeply dipping limestone. The limestone when heated gives off a petroleum odor on the strength of which Harris, years ago, advised drilling for oil. In some domes, the cap rock has not been found as yet. This is true of Goose Creek, and Edgerly especially, in both of which wells have gone down over 5,000 feet without striking limestone. As regards thickness

the cap rock is found to be extremely variable. Perhaps the thickest cap is found at Sulphur, where 1,100 feet were found. The average thickness is probably about 350 feet. Of the 1,100 feet at Sulphur, about 900 feet consist of anhydrite, the remainder being made up of sulphur and limestone. Figure 161 shows the position of this cap and the thickness of the three members. It also shows that the top of the cap rock is quite irregular. The top of the salt will be seen to be almost flat.

Another thick cap is found on the Hockley Dome. In this dome the limestone cap is 200 feet thick and the anhydrite about 800 feet thick. It will be noted again that the top of the salt is perfectly flat. The limestone is very porous here and this feature is noted in many domes. Solution is probably accountable for this porosity and produces an excellent oil reservoir as a result of it. Spindletop, Saratoga, and Sour Lake domes produce oil from the cap rock.

Stratigraphy.—The strata involved in the coastal salt domes all belong to the Tertiary and Quaternary systems. Inasmuch as most of the domes are within 150 miles of the present coast line, Pleistocene deposits and the youngest Tertiary deposits crop out around the domes. The areal geology is indicated on the map (Fig. 157), and shows that most of the domes lie in the out-

TABLE OF FORMATION NAMES USED IN COASTAL SALT-DOME DISTRICT[1]

Series	Southwest Texas		Southeast Texas		South Louisiana	
	Formation	Thickness, feet	Formation	Thickness, feet	Formation	Thickness, feet
Pleistocene	Beaumont clay	300 to 900	Beaumont clay Lissie gravel	1,500	Beaumont clay Lissie gravel	1,500
	Lissie gravel	500 to 1,000				
Pliocene	Reynosa	500 to 1,500	Lafayette	1,800	Citronelle	50 to 400
	Lagarto	350 to 650				
	Lapara	75 to 450				
Miocene	Oakville	180 to 600	Fleming	3,000	Pascagoula	250 to 400
Oligocene					Hattiesburg	325
	Catahoula	0 to 1,200	Catahoula	200	Catahoula	700
	(?)	235 to 700	Middle Oligocene	900	(?)	
Eocene	Jackson	480 to 800	Jackson	700	Jackson	100 to 160
	Yegua	475 to 1,050			Yegua	400 to 800

[1] See APPLIN, ELLISOR, KNICKER, DUMBLE, HARRIS, and VEATCH.

crop belt of the Pleistocene-Beaumont clay, while a few lie within the Pliocene belt.

The Tertiary and Quaternary formations, listed in the table above, consist for the most part of relatively soft, unconsolidated sands and clays. Also, they are mostly non-marine sediments grading shoreward, *i.e.*, toward the present shore line into marine sediments. They are therefore made up of palustrine, lacustrine, and fluviatile sediments toward the north and partly of marine sediments toward the south. In general, they are thinner toward the north away from the shore line because of overlap, and thicker toward the present shore line. For instance, on the outcrop of the Oligocene (see Fig. 157) the strata all belong to upper-Oligocene horizons, whereas farther south beneath the surface, middle-Oligocene horizons are found in the well cuttings. Being of diverse origin and largely continental in nature, these sediments do not extend horizontally for any great distance with the same lithological character, so that correlation from place to place or even from well to well in a given pool is almost impossible. Sands, of course, are most unreliable and they can be traced only in zones. The clays and gumbos are somewhat more reliable and can often be traced for some distance in a broad way by color or other characteristic.

Micropaleontology has been of inestimable value to the geologists who have worked in the coastal salt-dome fields. Collections were made on the outcrop, special care being taken to secure representative groups of foraminifera. These were carefully studied and labeled and then sectioned off into typical zones. Well cuttings which also yield foraminifera in abundance from certain horizons may then be compared to the outcrop zones. In this manner, it was soon found that the subsurface zones and horizons were more numerous than the ones exposed on the outcrop. Little attention is paid to Pleistocene material as a rule for no oil has been found in rocks of that age. Similarly, the Pliocene has received but scant attention, for it also is relatively unimportant. The Miocene strata have furnished the most oil and, therefore, greatest care and refinement has been devoted to that part of the section. The Oligocene is also very important and has been very well worked up, so that fairly close correlations may be made. The Jackson strata are very fossiliferous in respect to microorganisms and, therefore, much is also known about that formation, even though it is not often reached by the drill.

The Beaumont clay consists of calcareous clay with thin lenses of sand and sandy clay. The Lissie gravel is composed of gravels and coarse sands with pockets of red clay. The Pliocene is made up of sands, clays, and conglomerates. The Miocene in the greater part of the oil-producing area consists of soft clay or gumbo which is variously colored. The tan, red, and purple zones often help greatly in correlation. It is mostly non-marine, but occasional streaks of marine clays are met with. The marine streaks become more frequent and thicker toward the present coast line. Three well-defined faunas have been differentiated by the oil-company paleontologists. They are the Rotalia, Truncatulina, and Globigerina zones, named in each case after the predominant element in the group of forms characteristic of each zone. Miocene strata reach great thicknesses in the well sections of the coastal area.

The Oligocene strata consist of non-marine sands and clays which are non-calcareous on the outcrop. Under cover they become more calcareous and some marine streaks appear in the section. In the well cuttings strata of middle-Oligocene age have also been recognized and found to be quite thick. These middle-Oligocene sediments consist for the most part of clays with a grey or green color. They are divisible into three units on paleontologic grounds, which are called the Discorbis, the Heterostegina, and the Marginulina zones. Quite a number of the salt domes produce oil from this part of the section. Goose Creek leads in production and produces from all three zones. Damon Mound produces some from three zones. Hull and Humble produce from two zones, while West Columbia, Barber's Hill, Sour Lake, Pierce Junction, and Stratton Ridge produce from only the middle zone.

The strata of Jackson age differ from the others in lithology and also in fossil content. The bright colors are missing and grey to black colors predominate. Clays and gumbos again make up the largest part of the section, but sandy zones appear at many points in the formation. Only the upper part of the formation is exposed on the outcrop. The Jackson has been identified by its characteristic fauna in the following domes: Hull, Sour Lake, Saratoga, Humble, Hockley, Blue Ridge, Damon Mound, West Columbia, Hoskins Mound, Markham, Brenham, Piedras Pintas, and Palangana (in Texas) and Vinton (in Louisiana).

Producing Horizons.—Oil and gas occur in many horizons on the salt domes of the coastal area. Any porous stratum in

the section is likely to contain oil, gas, or water. One unusual horizon is the cap rock of the dome. The top of the cap rock very often consists of cavernous and porous limestone which is capable of holding great quantities of the fluids. An outstanding example of a dome in which the cap rock is the producing horizon is Spindletop. Some oil is secured from a sand which lies at a distance of about 120 feet above the cap rock, but until very recently practically all the oil came from the cap rock. The enormous amount stored up in this reservoir is almost unbelieveable, for it has produced over 190,000 barrels per acre—a record which has not been equaled anywhere else except on another salt dome. One well (the Heywood Bros., No. 2) came in for a production of 96,000 barrels per day and in 10 months had put 1,395,000 barrels of oil into the pipe lines. The gravity of the oil is between 21 and 23° Bé.

Some domes produce oil from sands above the cap rock. The outstanding example in this class is Goose Creek, located a few miles east of Houston. The first sand on this dome is found at a depth of about 1,000 feet. The next sandy zone lies at a depth of 2,300 to 2,500 feet. In this zone many sands carry oil, but water is also present and causes a great deal of trouble when wells are about to be brought in. The third zone lying at a depth of from 2,800 to 3,100 feet is the most important zone, for in it the sands are more extensive than in the other zones and as a rule thicker. Many sands in this zone are 80 to 100 feet thick. The sands between the second and third zone carry only water. Another series of good sands has been discovered at 3,300 to 3,600 feet. Finally, the deepest zone of producing sands lies at a depth of 4,200 feet. The sands in this zone are very lenticular. They vary from 30 and 40 feet to practically nothing within a short distance. All sands are shown in Fig. 162 which is taken from Minor's excellent article on Goose Creek.

The production at Goose Creek has been high, which is not surprising considering the number of sands present. Up to the end of 1923, it amounted to 55,000 barrels per acre. The total to the end of 1929 from this dome amounts to 65,000,000 barrels of oil. The gravity of the oil shows a variation from sand to sand the higher gravity oil being found lower down. The upper sands produce oil of 21° Bé. gravity and the lowest sands produce oil of 27° Bé. gravity. Some wells of gusher proportions were drilled here. One well made 35,000 barrels per day at 3,007 feet.

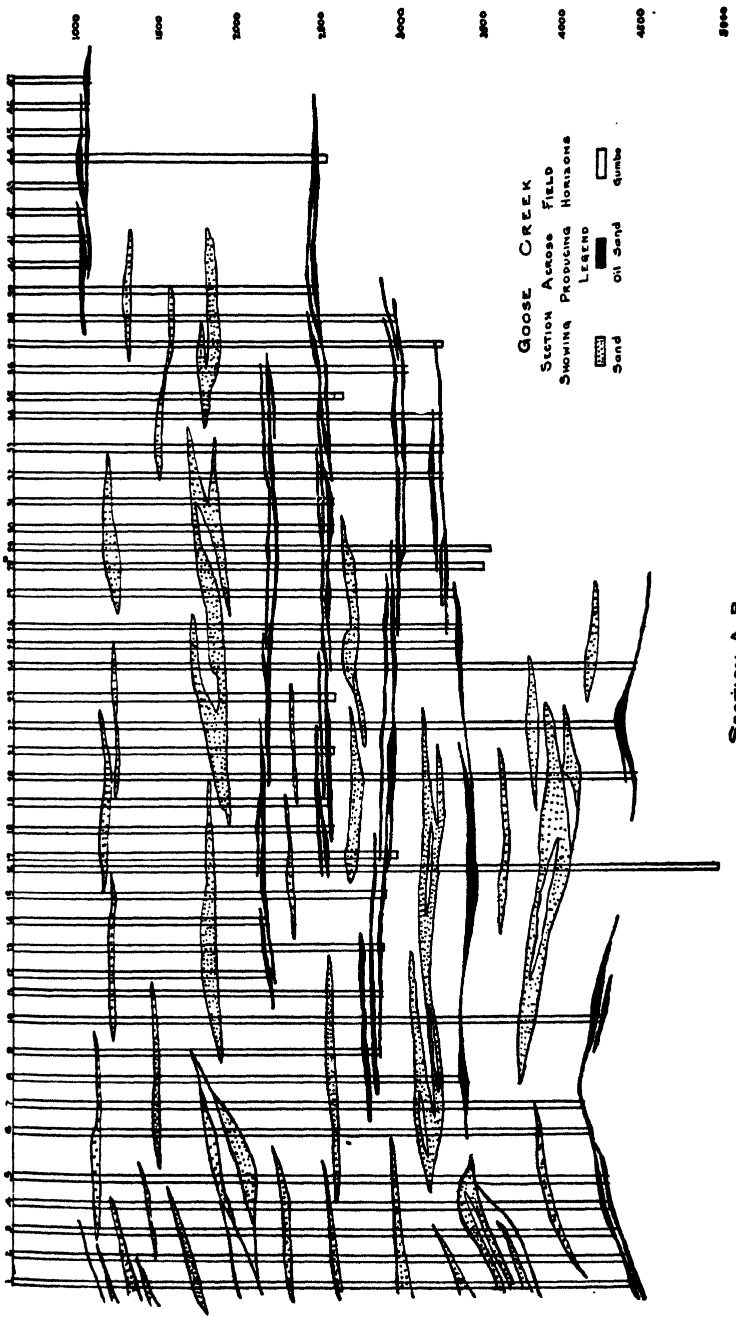

Fig. 162.—Northeast to southwest section across Goose Creek. (*After Minor, Bull. A.A.P.G.*, 9, 292, Fig. 4.)

The deepest well in the field drilled to a depth of 5,002 feet failed to locate the cap rock of the salt dome. Nevertheless, the restricted area of production, the steep dip of the sands on the edge of the field, and the surface indications, lead to the assumption that Goose Creek is a real salt dome. A very interesting feature about this dome is the fact that it has shown a notable subsidence since oil has been taken out of it. It used to lie slightly above sea level, but now the producing area is submerged from 2 to 3 feet below sea level. Minor believes that the removal of the fluids from the sands has allowed the soft gumbos and clays to settle and compress the sands.

A third set of producing horizons is found on the flanks of the domes. This is perhaps the most common type of oil and gas occurrence. The sands which produce on the flanks usually dip pretty steeply away from the dome, so that the producing area takes the shape of a circle or band of narrow width. Oftentimes, only certain sides of a dome are productive on the flanks because of the great lenticularity of the sands. This is the case, for example, at Damon Mound. One small producing area is located on the northeast side and the larger, better producing area is located on the southwestern side. As is usual with the oil domes, a disheartening number of unsuccessful wells had to be drilled on the dome and around the periphery before these producing areas were defined. Nevertheless the per-acre production of over 20,000 barrels makes it seem worth while. The total oil production from this dome to the end of 1929 amounted to over 7,000,000 barrels, practically all of which came from the sandy zones in the Oligocene series. The sands are so variable that they seem to be but mixtures of sand, clay, and shale. The gravity of the oil varies from 19 to 25° Bé., the higher gravity being found at the greater depth. The deepest producing horizon lies at 4,600 feet.

In summary, it may be stated that most of the production found up to date on the salt domes or around them has come from *Miocene* and *Oligocene sands*. In a few domes, the *cap rock* has been very productive but the total production for cap rock does not compare with the total obtained from stratified sands in the section. The deepest production is from sandy layers in the Jackson formation of Eocene age.

Relation of Production to Structure.—The relationship of production to structure is very striking in the case of the salt

domes. On all domes there is evidence of vertical movement of the central salt core. In some cases this has resulted in arching the strata to form a quaquaversal dome, but in other cases the strata have been ruptured and punctured in such a way that the ruptured edges impinge against the salt mass. In the first case, that of arching, the oil has migrated from surrounding lower areas and accumulated in the highest parts of the reservoir sands, strictly according to the anticlinal theory of occurrence. In the other case, that of ruptured strata, it must be supposed that the salt mass has acted as an impervious barrier to the migration of the oil and accompanying waters, and has caused them to pond up against the periphery of the salt plug. The fact that the sands are all very lenticular, and part of this lenticularity may be due to the upward drag and disturbance caused by the salt plug must also be considered. They may therefore be looked upon as similar to sands pinching out up the dip.

Sand Correlation.—Because of the marked lenticularity of sands in the district, it was found very difficult to make correlations. Minor developed a method based on the chemical composition of oil field waters which has proved eminently satisfactory. At first, a complete analysis of all waters was made, but comparisons soon showed that most constituents are constant within small limits except the amount of chlorine. The amount of chlorine increases with depth, but remains constant within a given stratum or level to within 0.2 of 1 per cent over a distance of more than a mile. These two facts make it possible to form an opinion about the stratigraphic position of a sand in a very few minutes as the chlorine content may be quickly determined in the field. Another, and a very important practical application of this principle, is to determine where the water comes from which develops in wells on account of casing leaks, poor casing seats, faulty seals, etc. Many analyses indicate that the chlorine content of the water ranges from fresh water near the surface to as much as 6½ per cent of chlorine in sands lying at a depth of 4,200 feet below the surface. Below the 2,000-foot level, the average increase is quite uniform and amounts to 0.3 of 1 per cent for every 100 feet of depth. This method is most sensitive in domes where the salt plug lies at great depth. Where the salt has intruded the sediments, it is found that each sand shows an increase as the salt plug is approached. Where the sand touches the salt core it reaches saturation.

A subsurface contour map made by means of chlorine content of the sands was made by Minor on the Goose Creek dome. It conforms very closely to the area of actual production. Subsurface faults have also been found by means of comparing the chlorine content of sands. This is brought out by Fig. 163 which shows a portion of the Edgerly Dome in Louisiana. The principal producing levels in this field are the 2,700-, 2,900-, and 3,100-foot levels. An area of 10 to 15 acres in the southeastern portion of the field produces from the 2,300-foot level. The salt concentration in the 2,300-foot level corresponds to that

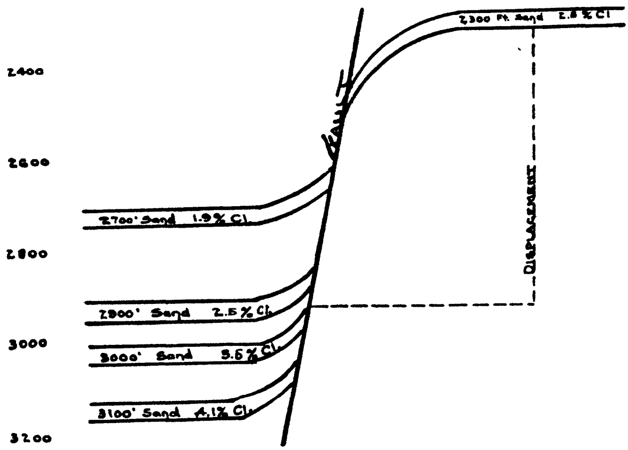

FIG. 163.—Diagram of faulted area located by means of chlorine content of sands. (*After Minor, Bull.* A.A.P.G., **9**, 501, Fig. 3.)

of the 2,900-foot level, showing an uplift of 300 to 500 feet, or faulting with that amount of displacement. This water correlation may be checked by lithologic correlation of a violet gumbo which appears in the section below the 3,000-foot level.

Interior Domes of Texas and Louisiana.—The interior domes of Louisiana have been very fully described by Spooner[1] and those of northeast Texas by Powers.[1] The domes in Louisiana are all located some distance from the coastal domes and in the northeastern part of the state. Figure 157, p. 388, shows the location of them as well as their tectonic setting. They are placed along the eastern edge of the Sabine uplift along a trend which is about northwest and southeast. All are located in Bienville and Winn

[1] See Bibliography. See also RENICK.

parishes within a strip 75 miles long and 35 miles wide. The names of the domes discovered up to date are as follows: Vacherie, Arcadia, Rayburn's, King's and Prothro in Bienville Parish and Coochie Brake, Cedar Creek, Winnfield Quarry, Price's and Drake's in Winn Parish. The most common form of topographic expression in these domes is that of a central depression with an encircling range of low hills. Surface evidence of the salt is furnished by salt licks, or salines around the periphery of the central basin, springs of mineralized water, steeply tilted rocks, and formations cropping out which should normally be found only at great depth.

NAME OF DOME	CAP ROCK		SALT CORE			TOPOGRAPHIC EXPRESSION	GEOLOGY		AMOUNT OF UPLIFT IN FEET	DIAMETER OF UPLIFT IN MILES	WELLS	
	FOUND	DEPTH IN FEET	FOUND	DEPTH IN FEET	DIAMETER OF CORE IN MILES		NORMAL SURFACE FORMATION	OLDEST FORMATION EXPOSED AT THE SURFACE			DEEPEST ON TOP OF DOME	DEEPEST ON THE SIDE OF DOME
ARCADIA	X	1982	X	1400	1	NONE	ST MAURICE	ARKADELPHIA	2000	4	2000	4012
BISTINEAU	X	1975	X	1900	3/4	CENTRAL SALINE	CANE RIVER	MARLBROOK	2000	3	2305 (a)	3245
CEDAR CREEK	X	700	No		3/4	CENTRAL SALINE	YEGUA	ST MAURICE	3000	3	1120	2650
COOCHIE BRAKE	No		No		—	CENTRAL DEPRESSION	YEGUA	ST MAURICE	(b) —	2 3/4	NONE	3100
DRAKE'S	X	290	X	900	3/4	CENTRAL SALINE	SPARTA SAND	WILCOX	2000	3	2263	1510
KING'S	X	161	X	172	3/4	CENTRAL SALINE	CANE RIVER	MARLBROOK	2100	3	404	2506
PRICE'S	No		No		1/2	CENTRAL HILL	SPARTA SAND	WILCOX	2000	2 3/4	NONE	2134
PROTHRO	No		No		3/4	CENTRAL DEPRESSION	SPARTA SAND	BLOSSOM SAND	2800	3 1/2	NONE	NONE
RAYBURNS	X	86	X	115	1/2	CENTRAL SALINE	SPARTA SAND	BLOSSOM SAND	2700	3	277	3003
VACHERIE	X	646	X	777	1/2-3/4	CENTRAL DEPRESSION	SPARTA SAND	ARKADELPHIA	1600	4 1/2	847	2556
WINNFIELD	X	On surface	X	980	3/4	CENTRAL DEPRESSION	YEGUA	WILCOX	(b)	3	1100	4021
SIKES	No		No		—	NONE	YEGUA	SPARTA SAND	(c)	3	NONE	4046

A short distance down the flank (b) Uplift greater than in outcrops (c) Uplift not determined but amounts to several hundred feet

FIG. 164.—Table giving the essential characteristics of the interior salt domes of Louisiana. (*After Spooner, Bull.* A.A.P.G., **10**, 224, Fig. 4.)

The stratigraphic section for northern Louisiana is given on page 383.

On some of the domes the outcropping strata are magnificently exposed for study. For instance, on the Prothro dome the finest Tertiary section in the whole district is to be seen, including a goodly portion of the Cretaceous down to the Bingen sand, with volcanic ash interbedded. The occurrence of the Bingen at this point indicates an uplift of the salt plug amounting to about 3,000 feet. The first mention of Cretaceous rocks in northern Louisiana was made as a result of finding Cretaceous fossils around King's dome. Figure 164 will give the reader a convenient summary of essential characteristics of the interior domes of Louisiana. It shows, among other data, the surface geologic formation which would be normal to each and the oldest formation exposed at the surface.

The structure of the interior domes is very similar to that of the coastal domes except that the amount of uplift on each is perhaps more definitely measureable and capable of proof. Figure 165 shows the structure of one of the domes. It is perhaps the most interesting one for a number of reasons. For one thing, the presence of peripheral faults is clearly brought out. This is a common feature and the reason why it is more pronounced in the interior domes than the coastal domes lies in the nature of the surface formations. The coastal domes have soft gumbos and clays overlying them, whereas the interior domes have a large proportion of hard and brittle layers such as limestone and chalk which are capable of maintaining a fault. Another very interesting feature about this dome is the presence of the Washita conglomerate on the top of the cap rock. It is a fossilif-

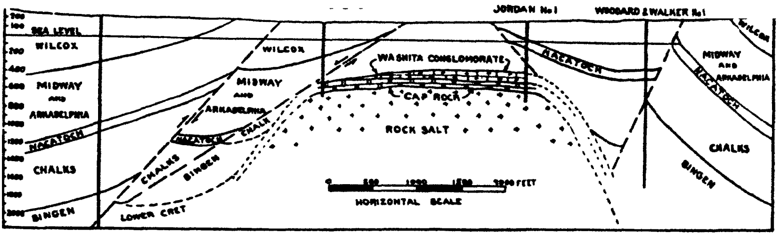

FIG. 165.—Cross-section of Vacherie salt dome showing faulting of sedimentary beds around the salt core. (*After Spooner, Bull.* A.A.P.G., **10**, 245, Fig. 10.)

erous conglomerate made up of well-rounded red, blue, and green limestone pebbles, smoky quartz and chert pebbles, all firmly cemented with calcite. It has a thickness of 134 feet and the contained fossils indicate that it is equivalent to the basal Washita of the Texas Cretaceous section. The same rock in the same position was found on the Arcadia dome also. A well drilled on the flank of the Vacherie dome found rocks of upper Washita age at a depth about 2,000 feet lower than the basal Washita on the cap rock.

The salt core in the Vacherie dome has a diameter of about 2,500 feet and has been entered by a number of wells. The cap rock consists of anhydrite and has a thickness of 120 feet. The amount of vertical movement indicated by the top of the salt plug and the associated rocks is 1,600 feet and affects an area of 4 square miles. The peripheral faulting on this dome is more pronounced than on the others. On one of the domes the cap

rock is exposed. This is the Winnfield Quarry dome, so called because of the quarry of limestone which was used years ago and is still used. It is estimated that over 1,000,000 tons of limestone have been removed from the area. In the quarry 70 feet of limestone is exposed, but its thickness is evidently much greater, for in one well about 1,000 feet of limestone was penetrated. The limestone is coarsely crystalline, with thin grey bands running through it. These bands may be continuous, twisted, faulted, and discontinuous. The rock is full of cavities, large and small.

The location of the interior domes of Texas is shown in Fig. 139 on page 348. The summary of essential characteristics of each of the domes in the district is given in table form below. The list includes Grand Saline, Steen, Brooks, Keechi, Palestine, and Butler. Since this list was compiled about 12 other salt domes have been found in northeastern Texas. These are listed and briefly described by Renick. The first one to be discovered is the Boggy Creek dome in northeastern Cherokee County (1924). When production was found on this dome in March, 1927, it started an intensive search for similar domes (by means of seismographs) which was rewarded with the finding of at least ten new and three possible ones. Five of the domes have been tested with the drill and salt or cap rock has been found in them at depths varying from 500 to 1,600 feet. The producing sand in the Boggy Creek dome is the Woodbine. Fifteen wells have been drilled to date and two producers secured. The thickness of the Woodbine is 538 feet in one of the dry holes of which 80 per cent is made up of sand and many of the sandy zones are saturated with oil. The gravity of the oil is high when it comes from the well but drops to 28° Bé. when exposed to the air.

Powers states that the interior domes of Texas are all cylindrical plugs over 1 mile in height with a diameter of ½ to 1½ miles within 3,000 feet of the surface. At Grand Saline, for instance, the top of the salt was reached at 306 feet, whereas a well ½ mile removed failed to reach salt at a depth of 3,842 feet. Like the coastal domes the top of the salt has been dissolved and reduced to a perfectly flat surface. One of the most interesting domes in Texas is the Palestine dome a cross-section of which is shown in Fig. 166. It shows a large area of uplift owing to the conical shape of the salt core. Fragments of lower Cretaceous limestone are shown at the surface in detached blocks, indicating that they

Salt dome	Salt core					Cap rock		Saline, licks, or lake		Wells		Geology		Amount uplift strata	Diameter area uplifted
	Found	Shallowest known depth, feet	Top eroded	Diameter miles	Mined during Civil War	Found	Depth, feet	Central	Circular around Central Hill	Deepest on top dome	Deepest on side dome	Normal surface formation	Oldest formation cropping out	Feet	Miles
Texas:															
Grand Saline	X	235	Yes	1¼	Yes	X	188	X	......	520	3,842	Wilcox	Wilcox	500	2½
Steen	X	300(?)	Yes	1	Yes	X	75	X	......	600(?)	2,630	Mt. Selman	Wilcox	500	3
Brooks	X	220	Yes	1½	Yes	X	195	X	......	429	3,193	Mt. Selman	Austin	4,300	3
Keechi	X	2,162	(?)	1	No	No	......	....	......	3,170	3,048	Mt. Selman	Taylor	3,500	3½
Palestine	X	122	Yes	¾	Yes	X	120(?)	X	......	700	......	Mt. Selman	Buda	5,500	4¼
Butler	X	312	(?)	1¼	No	(?)	......	X	X	1,200	1,220	Wilcox	Navarro	2,500	3½
Louisiana:															
Bistineau	X	1,862	Yes	1½	Yes	X	1,420	X	......	2,305	3,245	St. Maurice	Marlbrook	1,500	4
Vacherie	X	777	No	1 by 1½	No	X	658	X	......	897	2,558	St. Maurice	Arkadelphia	1,500	3 by 4
Arcadia	X	1,400	No	1½	No	X	1,375	X	......	4,012	3,450	St. Maurice	Arkadelphia	2,350	4
Rayburn	X	115	Yes	¾	Yes	X	At surface	X	......	277	3,003	St. Maurice	Blossom	2,200(?)	3
King's	X	175	Yes	1	Yes	X	160	X	......	136	2,225	St. Maurice	Marlbrook	2,000	3
Price's	X	1,300(?)	(?)	¾	Yes	X	1,100(?)	....	X	None	(?)	St. Maurice	Wilcox	1,500	2
Prothero	....	......	(?)	1 by 1¼	No	No	......	X	......	None	None	St. Maurice	Blossom	3,000	2½
Drake's	X	900	Yes	1	Yes	X	290	X	......	2,312	1,510	St. Maurice	Wilcox	1,500	2½
Winnfield	X	999	No	1½	No	X	At surface	X	......	1,100	4,021	Cockfield	Wilcox	2,000	2½
Cedar Creek	....	......	(?)	1	Yes	X	801	X	......	700	3,150	Cockfield	St. Maurice	1,500	3
Coochie Brake	....	......	....	1	No	No	......	X	......	None	3,100	Cockfield	St. Maurice?	1,500	2½
Clear Lake	X	234(?)	(?)	1	No	(?)	......	X	......	......	3,463	Cockfield	St. Maurice	1,500(?)	2½
Gibsland	....	1,238	....	....	No	X	1,142	....	......	1,520	......	St. Maurice	....	1,000	2

The location of the Louisiana domes is as follows: Bistineau, S. 35, 36, T. 18 N., R. 10 W.; Vacherie, S. 16, T. 17 N., R. 8 W.; Arcadia, S. 29, T. 18 N., R. 5 W.; Rayburn, S. 31, T. 15 N. R. 5 W.; King's, S. 34, 35, T. 15 N., R. 8 W.; Price's, S. 30, T. 13 N. R. 4 W., and S. 25, T. 13 N., R. 5 W.; Prothero, S. 7, 8, 17, 18; T. 14 N., 6 W.; Drake, S. 20, 21, T. 12 N., R. 5 W.; Winnfield S. 19, T. 11 N., R. 3 W.; Cedar Creek, S. 30, 31, T. 11 N., R. 2 W.; Coochie Brake, S. 6, T. 9 N. R. 4 W.; Clear Lake, S. 28, 29, 32, 33, T. 11 N., R. 6 W.; Gibsland, S. 15, T. 18 N., R. 7 W. (discovered December 1925).

were torn off when the salt plug came up and brought to the surface with it. Similar blocks of Woodbine, Eagle Ford, and Austin chalk formations were brought up from a depth of a mile or more and may now be seen on the outcrop. The faulting at Palestine is more complex than that of other domes and seems to represent a series of underthrusts arcuate in form and so arranged that the Austin chalk and Navarro formations are repeated on the outcrop. Such underthrust shreds of formations may be carried upward by the salt to a great height and thousands of feet above the point where the upturned edges of the same formation encircle the core. The striking alignment of the interior domes of Texas has already been discussed (see p. 351).

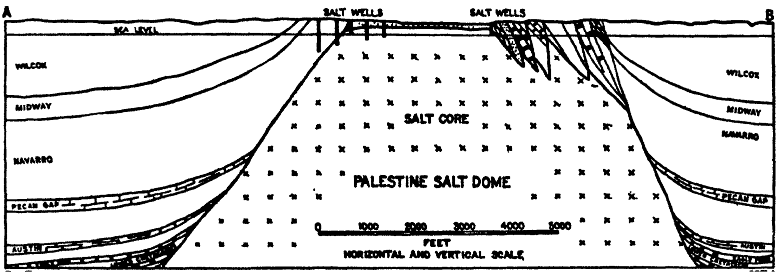

FIG. 166.—Cross-section of the Palestine dome from south to north. (*After Powers, Bull.* A.A.P.G., **10**, 47, Fig. 12.)

Origin of Salt Domes.—Barton and De Golyer have given us excellent summaries of the numerous theories and suggestions regarding the origin of salt domes and associated phenomena.[1] Barton has studied the European salt domes in Roumania and Germany at first hand and has summarized the information which has been published in many languages. De Golyer has brought together all the theories advanced by American students of salt domes and analyzed the points of weakness or strength in each. He groups the theories into four groups as follows: (1) the domes are old Cretaceous outliers in Tertiary seas; (2) the salt in the domes was deposited from solution; (3) the domes are due to volcanic phenomena; (4) the salt plug is due to intrusion by flowage resulting from pressure.

Hilgard, in 1870, was the first to suggest that the domes were probably outliers of Cretaceous rocks with a capping of recent deposits. Five years earlier, Owen had presented the view that

[1] See Bibliography.

the salt in the Five Islands' domes had been deposited from solution in sea water in barrier lagoons. In 1902, following up this line of thought, Hill suggested that hot saline solutions ascending from some depth had cooled so as to allow the salt to crystallize from solution. Fenneman, in 1904, first made the observation that the expansive force of crystallization might account for the upward push of the salt mass. Harris who had studied the salt domes very carefully for a number of years as state geologist of Louisiana was the first to explain the presence of the salt, the upward push of the salt, the tectonics of the domes, and the cap rock in a single harmonious theory. This theory still has a great many adherents and is very logical. In brief, it starts with artesian water entering saliferous rocks on the outcrop and taking into solution some of the salt as it slowly seeps through the strata. Becoming heated because of the great depth to which it descends solution is active. Finally, the water rises at points where old faults exist in the old rocks or perhaps at the intersection of faults, and, as the water rises, it cools and precipitates the dissolved substances. As new material is added at the bottom of the cone thus formed, the power of crystallization pushes the overlying portion of the cone upward. In time, the top of the salt reaches the zone of circulating fresh water and is beheaded. During the period of upward thrust of the salt the overlying strata are arched up and the adjacent rocks are tilted.

The volcanic theories were the earliest to be mentioned probably because of the similarity of a salt dome to an igneous neck or plug. Thomassey, in 1860, said that the material in the Five Island domes comes from a volcano of water, mud, and gas and that the salt results from evaporation of sea water by the volcanic heat. The next champion of the volcanic theory was Coste who, in 1903, suggested that all the salt-dome phenomena can be explained by volcanic emanations bringing water, gas, oil, salt, and sulphur toward the surface where they condensed because of loss of heat. He was supported in a general way by Hager, in 1904, and Veatch, in 1906.

Van der Gracht was the first to state that the salt probably has an intrusive origin. In 1918, Rogers discussed the previous theories at some length and took exception to Harris' theory chiefly because he showed that too much salt was concentrated in the domes to have been gathered and brought to the surface by circulating waters. Then he takes up van der Gracht's

idea that the salt behaves like a plastic mass and was squeezed up by lateral pressure, or was pushed up by orogenic forces. He states that he believes pressure of deeply buried rocks exerting lateral pressure is the most plausible explanation of the force which caused the salt to behave as it did, that isostatic adjustment is probably not the cause, and that pressure due to igneous intrusions is a possible cause. In addition, he also suggests that Permian rocks are the most likely original source of the salt.

In deciding what the history of the American domes has been, much light has come from a study of European domes, especially those of Roumania and Germany. Barton finds that the Roumanian domes resemble the American ones, if due allowance is made for their different structural setting. The American domes occur in a region which is characterized by regional dips of low angle, indicating that the rocks have suffered very little deformation. In Roumania, on the other hand, orogenic forces have been at work and the strata are compressed into folds. The salt, which was originally laid down in strata and interbedded with other sediments, was folded with the rest of the strata. Because of greater plasticity, it responded to deformative forces by a noticeable thickening on the anticlines and often broke through the strata at points of extreme pressure, forming what the Roumanians call "diapir" structures. As a result, the salt masses have a tendency to show an alignment along anticlinal lines and it is very evident that the structural control has been very effective. Elongated anticlinal ridges of salt are therefore more common in Roumania than domes.

In Germany, the dome type is common, but the other type of salt structure is also present. In fact, as a result of the extensive mining operations which have been carried on in Germany, salt structures are more intimately known and understood than anywhere else. German geologists on the basis of very careful observations have noted examples of every gradation between the original stratum of salt in undisturbed condition to the elongated ridge type, to the more complicated type in which there are bunches or knots along the anticlinal ridge, to the final stage of the "stock" or dome type. The last three are shown in Fig. 167. The upper diagram (*a*) shows the simple type of salt folded into a gentle anticline and partly eroded on the crest. The second drawing (*b*) shows the "Asse" type of salt structure in which the salt has doubled back on itself partly at the crest of the

anticline and formed local knots or bunches. The lowest diagram (*c*) shows the Hanoverian type of salt dome in which the salt structure is more or less cylindrical and has taken on the form of an igneous stock. The deformation of the overlying strata differs in each of these types. In (*a*) the strata are deformed slightly and parallel to the salt stratum; in (*b*) the strata are arched rather sharply and in concordance with the top of the salt

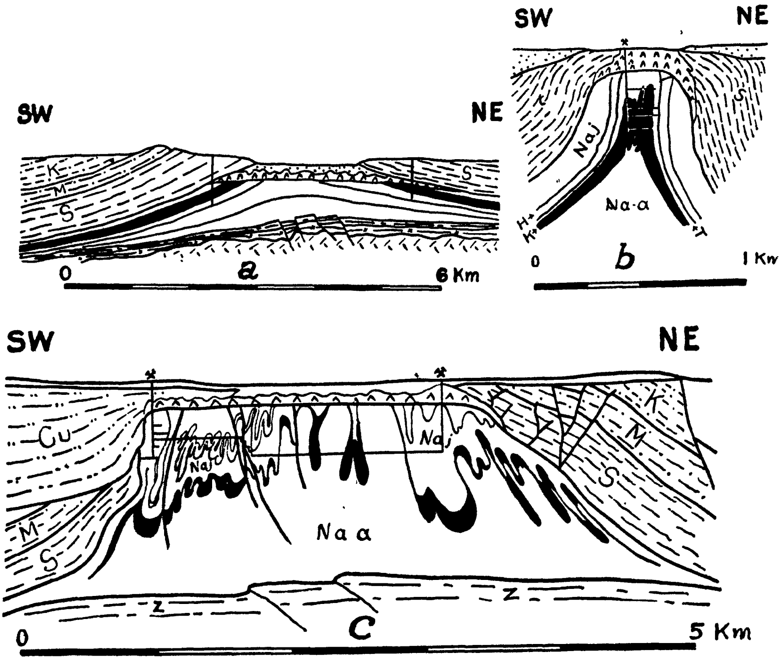

FIG. 167.—Types of German salt domes. (*After Barton, Bull.* A.A.P.G., **9**, 563, Fig. 6.)

mass; in (*c*) the strata are ruptured and the salt has pushed its way through the overlying strata.

A careful examination of the American salt domes indicates that they are not exactly like any of the European salt structures. They appear to be most closely allied to the Hanoverian type of salt structure of Germany and probably have had the same origin. It is very clear that the Hanoverian domes have resulted from the simpler types and are due to a greater amount of deformative pressure. Hence it is safe to assume that the American domes also are due to the plastic yielding of a salt mass under the influ-

ence of pressure. De Golyer[1] presents an excellent summary and working hypothesis of the origin of the American domes. The salt and anhydrite were deposited in lagoons of pre-Cretaceous age. Later, the salt strata and the adjacent strata were folded producing salt structures of the anticlinal ridge type. Then sediments of Cretaceous, Tertiary, and Recent ages were deposited upon them in normal succession and without deformation. During this time the salt structures continued to grow by punching through the anticlinal cover and also partly through the overlying blanket of sediments. In so doing they arched the strata at first, but later pushed the immediately overlying strata bodily through younger strata, lifting them thousands of feet in some cases. The conical form of almost circular cross-section assumed by the salt plug is explained as the form of easiest flow and least friction. The sediments adjacent to the core of salt were tilted away from the core into funnel-like structures. The cap rock is explained as due to solution of the top of the salt and the accumulation of the impurities, chiefly anhydrite, as a disc-like cap over the salt. Later, part of the anhydrite was changed to gypsum by hydration and this, in turn, was changed to limestone by reactions with circulating mineralized waters.

In discussing De Golyer's paper, Schuchert stated that there is no evidence in favor of the assumption of a Permian age for the salt. The old land mass of Llanoria evidently remained land during early Mesozoic time and up to the beginning of Comanchean time. The fact that anhydrite occurs in the Comanchean rocks of northern Louisiana, and red beds of Trinity age in southern Arkansas and northern Louisiana, makes it appear highly probable that the salt may be of Comanchean age. He also offered the hypothesis that the salt domes are due to the foundering of the old land mass of Llanoria during Cretaceous and early Tertiary time. In other words, the salt has risen on account of the pressure produced by differential block faulting.

Recent Domes.—The presence of topographic domes above the salt plug indicates that the upward push of the salt plug has in some cases extended into the present geological period. In some domes we find evidence of a completion of the upward thrust or at least of the cessation of this movement. Perhaps the clearest example of this is found in the Stratton Ridge dome,

[1] See Bibliography.

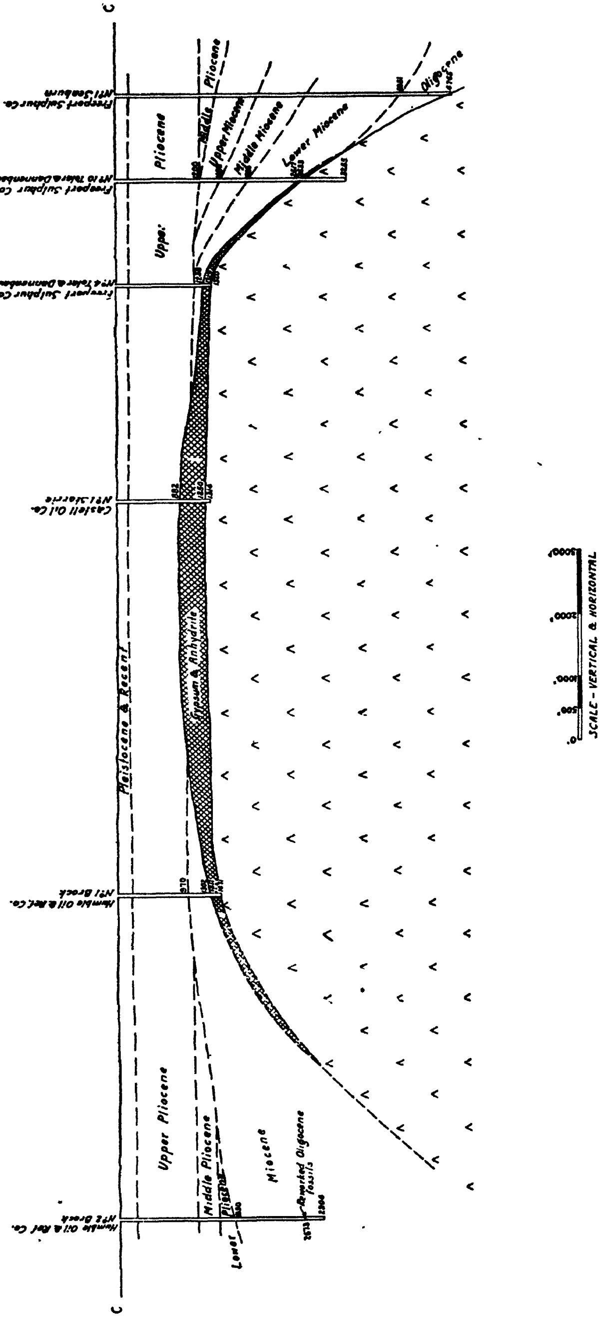

FIG. 168.—Structural cross-section through Stratton Ridge dome. (*After Applin, Bull.* A.A.P.G., **9**, 11, Fig. 3.)

located in Brazoria County, Texas. A cross-section of this dome is shown in Fig. 168. This section indicates that the top of the salt core is now about 3,000 feet above the punctured Oligocene strata. The Oligocene strata and the Miocene strata are seen to be steeply tilted against the side of the salt core. The Pliocene sediments overlie the Miocene unconformably, pass over the top of the salt and, furthermore, lie nearly flat. All this seems to indicate that the maximum amount of upward thrust of the salt took place between Oligocene time and early Pliocene time. The sediments of early Pliocene time are missing across the top of the dome.

Newly Discovered Domes.—During the last five years, the search for salt domes has been prosecuted with physical instruments that were not available previously. Quite a number of new domes are now known, the location of which was entirely unsuspected previously. In Louisiana, the following domes have been discovered: Bayou de Glaise, Lutcher, Bayou Henry, Grassette, Bayou Blue, Napoleonville, Darrow, and Sorrento. The last two are located east of the Mississippi River. Three new producing areas were also located, which may in time prove to be salt domes. These are Lockport and Sweet Lake as oil pools, and Terrebonne as a gas pool.

The first dome to be located by means of the seismograph was the Orchard dome in Fort Bend County, Texas. The first test on it encountered the cap rock at 375 feet. The Long Point dome in the same county was located by means of both the seismograph and the torsion balance. Tests with geophysical instruments were undertaken here on the strength of a sulphur spring seepage. Many other domes have been found by the same methods, among which are the Nash dome in Fort Bend County, the Fannette dome in Jefferson County, and the Hawkinsville dome in Matagorda County.

Production Statistics.—A great deal of oil and much gas has been taken from the coastal salt domes since 1901, when the first well came in on Spindletop. The domes which have contributed the most oil in Texas are the Humble, Spindletop, Sour Lake, West Columbia, Goose Creek, Hull, Batson, Orange, and Saratoga. All of those enumerated have produced more than 10,000,000 barrels up to the end of 1929 and they are named in order of relative total production. Humble has produced over 100,000,000 barrels Spindletop over 107,000,000 barrels; Sour Lake, 73,-

000,000; West Columbia over 71,000,000; Goose Creek nearly 67,000,000; Hull, 64,000,000; Batson about 35,000,000; Orange over 28,000,000; and Saratoga nearly 26,000,000 barrels. Other important domes in order of production are South Liberty, Pierce Junction, Damon Mound, Blue Ridge, Big Creek, Barbers Hill, and Boling.

In Louisiana, Jennings leads with a total of over 39,000,000 barrels produced from 1905 to 1929. Vinton produced over 32,000,000 in the same period, Edgerly 7,000,000 and Lockport 6,000,000. Only two other domes produced any important quantities besides those listed. They are East Hackberry with 2,500,000 and Sulphur with about 2,000,000 barrels. The only interior dome to produce oil is the Boggy Creek Dome in northeastern Cherokee County, Texas. Up to January, 1930, 1,400,000 barrels of oil were taken from this dome.

A remarkable feature about the production of the coastal domes is the high recovery per acre. In this respect, the Jennings Dome in Louisiana ranks supreme. Practically 90 per cent of the production at Jennings comes from 120 acres and, if this is used as a basis of figuring, the per-acre production amounts to nearly 300,000 barrels. If the total productive area is used in the calculations the production is about 153,000 barrels per acre at the end of 1929. This field had more big gushers than any other field with the possible exception of Humble and West Columbia. Twelve wells had an initial production of over 8,000 barrels and three were rated from 15,000 to 60,000. Spindletop ranks second with about 200,000 barrels per acre. West Columbia probably comes very close to this figure and may exceed it when the total ultimate production is known. Sour Lake and Vinton both exceed 130,000 barrels per acre, while Edgerly, Batson, and Saratoga exceed 50,000 by a considerable margin. The gravity of typical crude from these fields averages 21° Bé., though some is found as low as 11° and as high as 40° Bé.

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CHAPTER IX

OIL FIELDS OF WEST TEXAS BASIN PROVINCE

The most recent petroliferous province to be discovered by the drill and one which now appears to have enormous potentialities is the West Texas Basin province (see map, Fig. 169). As the name implies, the province is located in a structural basin in west Texas but includes also a part of southeastern New Mexico. This structural basin is filled with Permian sediments and is therefore often referred to as the *Permian basin.* Commercial quantities of oil were first obtained in this province when the first well was completed in the Westbrook pool in Mitchell County, which was in May, 1921. The area was not regarded with favor by geologists, because they knew that Permian strata were very thick in that part of Texas and Permian rocks were not expected to produce oil in quantity. Pure wildcatting based on hope is therefore responsible for opening this province. Another random well in a part of the province, some distance removed from the Westbrook well, came in with a production of 80 barrels per day in May, 1923, the first well in the Big Lake pool. This created far more interest, for the Westbrook wells had not been large. Nevertheless, the fact that both pools produced from a thick limestone was not encouraging. Furthermore, considerable amounts of sulphur were present in the oil and, therefore, caused difficulties for the refiner. Two years elapsed before another pool was discovered. In 1925, three pools were discovered. One of these was also a sheer wildcat venture, the World pool, in northern Crockett County (not many miles south of the Big Lake pool). Another was the McCamey pool in southwestern Upton County, and the third was the Wheat pool in southern Loving County. Meanwhile, in 1924, a pool had been discovered in the same province but in another state, the Artesia pool in northern Eddy County, New Mexico.

In 1926, four very remarkable pools were located. In April of that year the Chalk pool in southeastern Howard County was found. This pool produced over 22,000,000 barrels up to the

end of 1929. In May, the Church and Fields pool, which lies on the border between Upton and Crane counties, was discovered. The recovery from this pool was larger and amounted to over 54,000,000 barrels of oil by the end of 1929. In September, another pool was opened up nearby. This is the McCamey pool in southwestern Upton County, which produced about 16,000,000 barrels to January, 1930. The best one for the year was located, in November, near the center of Winkler County on

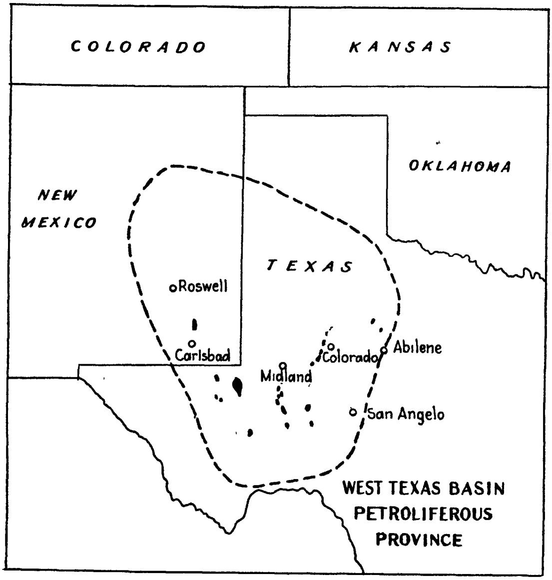

FIG. 169.—West Texas basin petroliferous province. Solid black indicates oil pools. Province outlined by dashes.

the west side of the basin. It is called the Hendricks pool and has produced 111,000,000 barrels of oil to January, 1930. The fourth pool, located in 1926, was the Yates which will probably go down in history as one of the wonder pools of the world. On July 1, 1929, the potential production was estimated to be 5,000,000 barrels per day from 313 wells scattered over an area of 17,000 acres. Under the proration plan adopted in the province the production is held down to 130,000 barrels per day. Another unusual feature about this field is the shallow depth of the producing horizon. The Maljamar pool in New Mexico east of the Artesia pool was also discovered in 1926.

The following counties in west Texas have one or more commercial wells at the present time: Crane, Concho, Crockett, Ector, Fisher, Garza, Glasscock, Howard, Jones, Loving, Mitchell, Pecos, Reagan, Runnels, Scurry, Sterling, Upton, Val Verde, and Winkler.

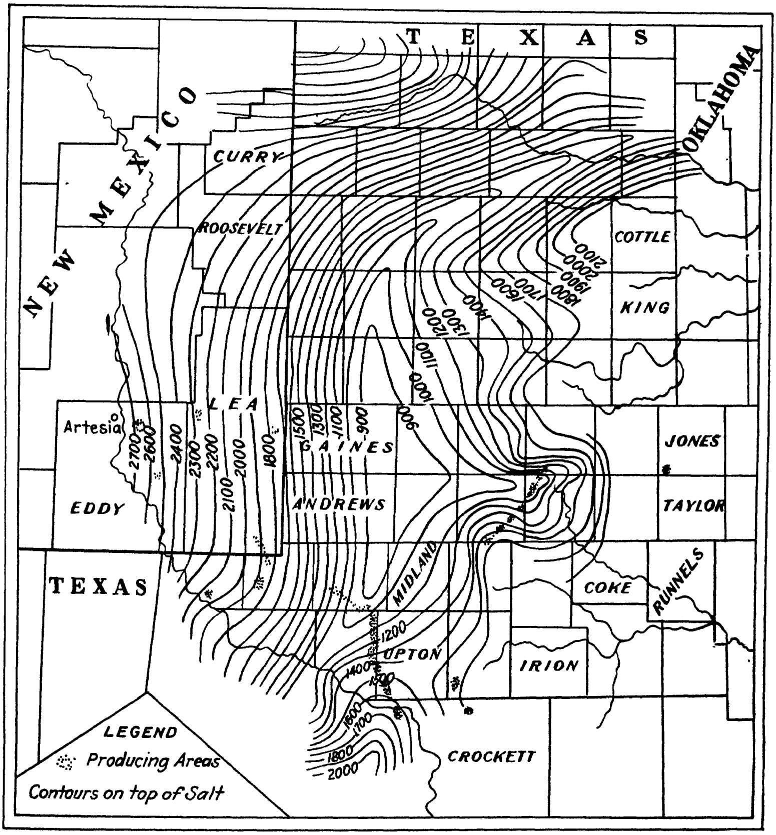

FIG. 170.—Map of western Texas and southeastern New Mexico showing general structure of top of salt beds. (*After Hoots, U. S. Geol. Survey Bull.* 780 B, Pl. XVII, in pocket.)

Tectonics.—The largest and the controlling tectonic element in this province is a syncline trending nearly north and south from the Pecos River in southern Crane County to Hockley County and beyond. This syncline is shown in Fig. 170 which is taken from Hoots, report on the geology of western Texas and southeastern New Mexico. The control for this structure map is

furnished by the top of the salt in a large number of wells. It will be noted that the control is practically wanting in the northern and northwestern part of the syncline. When more data are available it will probably be found that this syncline trends north only to Lamb County and there unites with an east-west syncline parallel to the Amarillo Mountains. Most of the wells up to date have been drilled in the eastern and southern parts of the syncline and hence the contour lines are most accurate there. This syncline may be called the West Texas basin.

On the east side, the basin is bounded by the Bend arch (see Fig. 134, p. 332); on the southeast, by the probable continuation of the Marathon arch; on the south and southwest, by the Glass, the Delaware and the Guadelupe Mountains; on the west and northwest, its boundaries are not defined as yet; on the north, it is bounded by the Amarillo Mountains (see p. 222) or possibly by another syncline which may be the Paloduro syncline of Gould.

Minor structural features superposed upon the basin have been discovered by drilling. In Fig. 170, a number of these structural modifications are shown. One of the most prominent is a plunging anticline which runs nearly east and west through Foard, Cottle, Motley, Floyd, and Hale counties. This appears to be the same as the Red River anticline described in Chap. VI, page 318. It may reflect a high buried ridge of Paleozoic or possibly pre-Cambrian rocks similar to the Wichita Mountains. Another anticline is clearly shown by the contour deflection in southern Kent and Garza counties and northern Scurry County. A third anticline is shown in northeastern Glasscock and southern Howard counties. Between the last two anticlines there is a very prominent syncline, which seems to be the deepest one along the east side of the basin. A very important structural element is shown by the contours in northeastern Pecos and southwestern Upton counties. This also is very likely a reflection of a buried mountain ridge below of Paleozoic strata. Three of the most prolific fields are located on this anticline or its extensions.

The depth of the basin is indicated to some extent by the thickness of the Permian salt. Where the states of New Mexico and Texas make a corner appears to be about the place where the salt is the thickest. Centering about that corner is an area in which the salt is over 1,000 feet thick. It will be noted that the western and southwestern edge of the basin is very narrow and abrupt. This has been interpreted by some geologists as due to

faulting, but very probably means simply that subsidence has been very rapid there. Usually one side of a geosyncline, the area next to the land mass which is supplying most of the material, sinks more rapidly than the other side.

Stratigraphy.—The succession of rocks in the West Texas Basin province involves chiefly Permian strata. Some Pennsylvanian strata have been encountered in a few wells at the edge of the basin and, above the Permian strata, Triassic, Comanchean, and Recent rocks occur. It will be noted that recent deposits of sand, caliche, and alluvium form the bulk of the surface exposures. The Comanchean rocks crop out in narrow ribbons within and about the periphery of the basin, while the older rocks appear in bands of greater width beyond them. The rocks on the opposite sides of the basin have been studied by different geologists at different times and have been given different names. It is not a simple matter to correlate these formations. The most recent attempts at correlation have been made by Willis[1] and Edwards.[2] The formations on the west side of the basin have been most exhaustively described by Blanchard and Davis[3] who made correlations for southeastern New Mexico and southwestern Texas for the surface and subsurface formations. Lloyd and Thompson did the same for the formations on the east side of the basin.[4] The table on p. 432 represents a composite of all these articles.

On the east side of the basin the *Wichita-Albany* formation is typically marine and consists of dolomitic limestone and blue shale. The overlying *Clear Fork* is a mixed marine and continental deposit, containing mostly red clastics, but also a little dolomite and blue shale. The *Double* Mountain consists of red beds and gypsum at the outcrop. When it is traced under cover toward the west by means of well logs it becomes more gypsiferous and saliferous. In its upper portion it contains the thick beds of salt which are so characteristic of the basin. In its lower portion it merges into the upper part of the *Big Lime.* The Clear Fork also becomes dolomitic limestone when traced into the basin. The red beds project into the limestone as wedges of considerable size and this facilitates correlation greatly. One of the prominent

[1] WILLIS, ROBIN, *Bull.* A.A.P.G., **13** (No. 8), 1001, August 1929.

[2] EDWARDS, E. C., *Bull.* A.A.P.G., **11**, 724, 1927.

[3] BLANCHARD and DAVIS, *Bull.* A.A.P.G., **13**, 988 and 999, 1929.

[4] LLOYD and THOMPSON, *Bull.* A.A.P.G., **13**, 948, 1929; CRANDALL, K. H., *Bull.* A.A.P.G., **13**, 929, 1929; KING and KING, *Bull.* A.A.P.G., **13**, 909, 1929; KEYTE, I. A., *Bull.* A.A.P.G., **13**, 904.

TABLE OF FORMATIONS IN WEST TEXAS BASIN

	West side	Thickness, feet	West side	Thickness, feet	Center	Thickness, feet	East side	Thickness, feet	
Permian	New Mexico		Texas						
Permian	Upper red beds		Upper red beds		Upper red beds	1,500	Quartermaster	300	Double Mountain
Permian	Rustler	500	Rustler	200	Rustler dolomite	200	Cloud chief gypsum	350	Double Mountain
Permian	Upper salt				Upper salt	2,000			Double Mountain
Permian	Anhydrite etc.		Castile	2,500	Anhydrite, etc.	1,200	Whitehorse sandstone	500	Double Mountain
Permian	Seven Rivers gypsum		Carlsbad	700					Double Mountain
Permian			Queen sand	200					Double Mountain
Permian	San Andres limestone	1,200	Lower Capitan		Big lime	2,000+	Dog Creek shale Blaine gypsum	600	Double Mountain
Permian	Glorieta sandstone	60	Delaware Mt. sand		(Dolomitic, with some sandstone near the top)		San Angelo sandstone		Double Mountain
Permian	Yeso gypsum	2,500	Bone spring limestone				Clear Fork	1,000	
Permian	Abo sandstone	1,000	Hueco limestone				Wichita-Albany	1,200	
Penn.	Magdalena						Cisco		

wedges occurs near the base of the Clear Fork, one near the middle of the same formation, and a third one at the base of the Double Mountain. The top of the *Big Lime* when projected to the outcrop is found to correspond to the *Blaine gypsum* on the east side of the basin and probably to the *Delaware* on the west side of the basin. Inasmuch as the Big Lime is the most reliable key horizon for subsurface correlation in the province and, since it contains the best oil-bearing horizons, it has received a great deal attention from geologists. At present, there is not complete agreement among the geologists who have done the most work in the province as to its exact counterparts elsewhere. It is believed, however, that the Big Lime of the Panhandle district of the Ouachita-Amarillo province is not the same as the Big Lime of the West Texas Basin province, as the latter lies somewhat higher stratigraphically, with its top about equal to the Blaine gypsum, and, therefore, within the Double Mountain formation. The Panhandle Big Lime is believed to be older and to correspond to the Wichita-Albany formation. Between the Panhandle district and the center of the West Texas basin the top of the Big Lime

transgresses stratigraphic horizons gradually. In other words, while salt and gypsum were being accumulated under arid conditions in the Panhandle district, dolomite was accumulating farther south, a condition which lasted well into Double Mountain time.

The salt, which accumulated in the West Texas basin later, reached its maximum thickness near the corner of New Mexico and Texas. It appears that the open sea lay in the direction of Trans-Pecos Texas and a low barrier (coral reef?) existed not far west of the Pecos River. The intermittent influx of sea water over this barrier supplied the inland sea with salts which were subsequently precipitated, when evaporation of water within the inland sea produced the proper concentration of salts. Near the edges of the basin intermingling of occasional surface water caused only gypsum and anhydrite to form. An increase of anhydrite over salt is also noticeable from the center of the basin toward the southwest. Subsidence of the basin must have been very gradual to allow over 1,000 feet of salt and associated materials to accumulate. An interesting feature about the salt deposits of the West Texas basin is the frequent finding of potash salts within the salt beds.[1]

The formations above and below the Permian are interesting, but not very important at present. In some wells the Trinity, Fredericksburg, and Washita, of Comanchean age are encountered. Beneath the Comanchean and below an unconformity some Triassic rocks have been found. In the center of the basin they form the surface strata and vary in thickness from 0 to 1,700 feet. They consist of dark red clay with interbedded layers of grey cross-bedded sandstone and coarse conglomerate. The sandstone is invariably micaceous. These beds were named, in 1890, by Cummins, the *Dockum* beds. The Triassic is separated from the Permian by an unconformity. All the formations discussed are shown in the diagram, Fig. 172.

Below the Permian rocks of the basin, Pennsylvanian rocks have been found in a few deep wells located near the eastern edge of the basin. A number have entered the Cisco formation and one entered the Bend formation. This well is located in Sterling County and found the base of the Cisco at 3,185 feet in depth. The Bend formation was identified from 3,735 to 4,143 feet. In the main part of the basin no wells have passed through

[1] See Hoots, pp. 48–54.

the Permian or the Big Lime, with the exception of the 8,250-foot well in the Big Lake pool.

Producing Horizons.—The best producing horizons in the West Texas Basin province are contained within the Big Lime. This limestone or dolomitic limestone has porous zones at various levels, and in these porous zones oil and gas and water have accumulated. In the Westbrook field one porous horizon lies at a depth of 2,400 feet near the top of the Clear Fork portion of the Big Lime (see Fig. 202) and another at a depth of about 3,000 feet near the base of the Clear Fork portion of the lime.

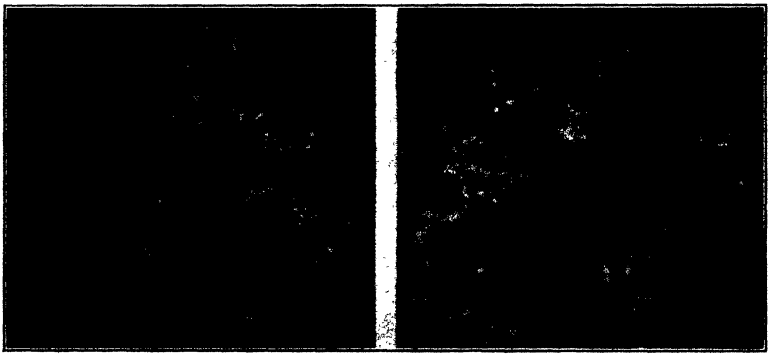

FIG. 171.—Individual oolites picked from well samples and porous dolomite from the producing horizon in the Big Lake pool. (*After Sellards and Patton, Bull.* A.A.P.G., **10**, 376, Fig. 6.)

There, the limestone is a dense, massive, brownish dolomite with small pore spaces. In the Chalk field southwest of the Westbrook field, there are three porous zones in the Big Lime. They lie at depths of 2,200, 2,500, and 3,000 feet from the surface. In most of the other fields only one porous pay zone has so far been exploited. The porous zones are usually from 10 to 60 feet thick and occur uniformly with certain vertical limits within the same pool. As a rule the best production has been obtained from porous zones lying within 500 feet of the top of the Big Lime. The shallowest depth to production is found in the Yates pool in Pecos County where wells of gusher proportions were found at 995 feet. In one field the producing horizon has been found to be oolitic limestone (see Fig. 171).

The cause of the porosity at various levels in the Big Lime is not easily explained. It has been suggested that it may be due to dolomitization. This is not likely, however, inasmuch as the

rock was in all probability laid down as a dolomite, a common type of deposit in an arid basin. Another, and more likely cause is that circulating waters have dissolved out some of the limestone as the presence of sulphur in the oil and also in the water lends support to this view.

Although the top of the Big Lime is most commonly used for correlation purposes and for purposes of determining structural conditions, maps made by different geologists are likely to differ because of the difficulty of determining the exact top of the Big Lime. Figure 172 illustrates the fact that the driller's log which is mostly used in making correlations is not reliable at all times and that a graphic log based on well samples is necessary for accurate work. In this log of a Yates field well the top of the Big Lime really lies below 1,500 feet according to the sample log, whereas it might have been placed from 500 to 700 feet higher according to the driller's log. The nature of the materials at and near the top of the Big Lime in various pools of the province is shown by Cartright in Fig. 173.

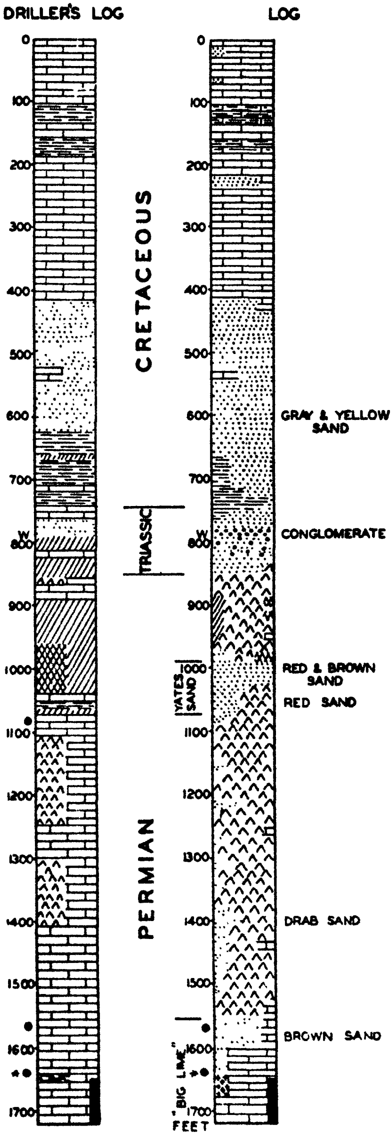

FIG. 172.—Log of Yates field well as reported by driller and as taken from samples. (*After Cartright, Oil Weekly*, p. 48, Jan. 25, 1929, Fig. 3.)

Oil has also been found above the top of the Big Lime. In the Chalk pool of Howard and Glasscock counties two of the five producing horizons are sandstones which lie in the Permian

redbed series about 400 and 800 feet above the Big Lime. They are very lenticular in character and very erratic in production. In the Yates pool of Pecos County some oil has been found in the

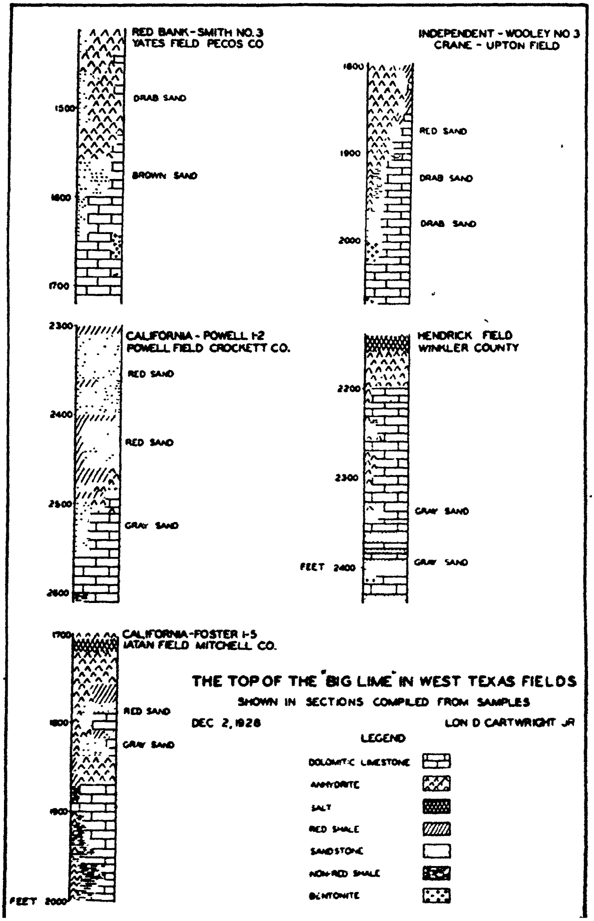

FIG. 173.—The top of the Big Lime in the west Texas fields shown in sections compiled from well samples. (*After Cartright, Oil Weekly*, p. 48, Jan. 25, 1929, Fig. 1.)

Yates sand which lies about 500 feet above the limestone. In the western part of the province the top of the Delaware Mountain formation, called the Delaware sand, sometimes contains oil. Whether this horizon should be correlated with the top of the Big Lime or not is a debatable question.

Relation of Structure to Production.—Surface structures in the West Texas basin are of no value as a rule in locating subsurface oil deposits. The Comanchean strata have a uniform dip toward the northwest and generally do not reflect any folding below, since they were laid down above an unconformity. There are a few exceptions to this generalization; for instance, the Yates pool was located by means of a dome in the surface rocks which are of Comanchean age.

In the subsurface, structure is usually shown on the top of the producing horizon or on the top of the Big Lime. The reason the Big Lime is not always used is because the driller often mistakes the anhydrite above the Big Lime for limestone. When enough wells have been drilled to permit contouring it usually develops that a subsurface anticline or dome is present. Figure 174 shows such an anticline in the Church and Fields-McElroy pools in Crane County. In this map the top of the Big Lime was used, and the contour interval is 25 feet with sea-level datum. It will be noted that the closure on the producing area amounts to over 300 feet. This field may be located on the same buried ridge on which the Yates field is located. The latter field is also located on a large dome which has greater dips than the surface dome. The Big Lake pool is located on a dome with a closure of at least 125 feet (see Fig. 177). Thus, judging by the information available at the present time the relation between production and structure is very close in this province. Recently Lloyd has shown that a giant coral reef has localized production to some extent.

Typical Pools.—The *Big Lake pool* is located in southwestern Reagan County and was discovered in June, 1915. The first well produced 80 barrels and found production at a depth of 3,000 feet. In this part of the province Comanchean rocks crop out at the surface with a thickness of about 300 feet. They consist of limestones of Georgetown, Edwards, Comanche Peak, and Walnut age, with about 100 feet of Trinity sandstone at the base. The Triassic rocks below the Comanchean consist of red and grey shale, sandstone, and conglomerate. The thickness of this system varies considerably because of the great erosional interval between the Triassic and the Permian. Evidently, the Permian surface was very irregular before Triassic sedimentation started. The Permian rocks are very thick, comprising 4,900 feet of strata, consisting of red beds with much

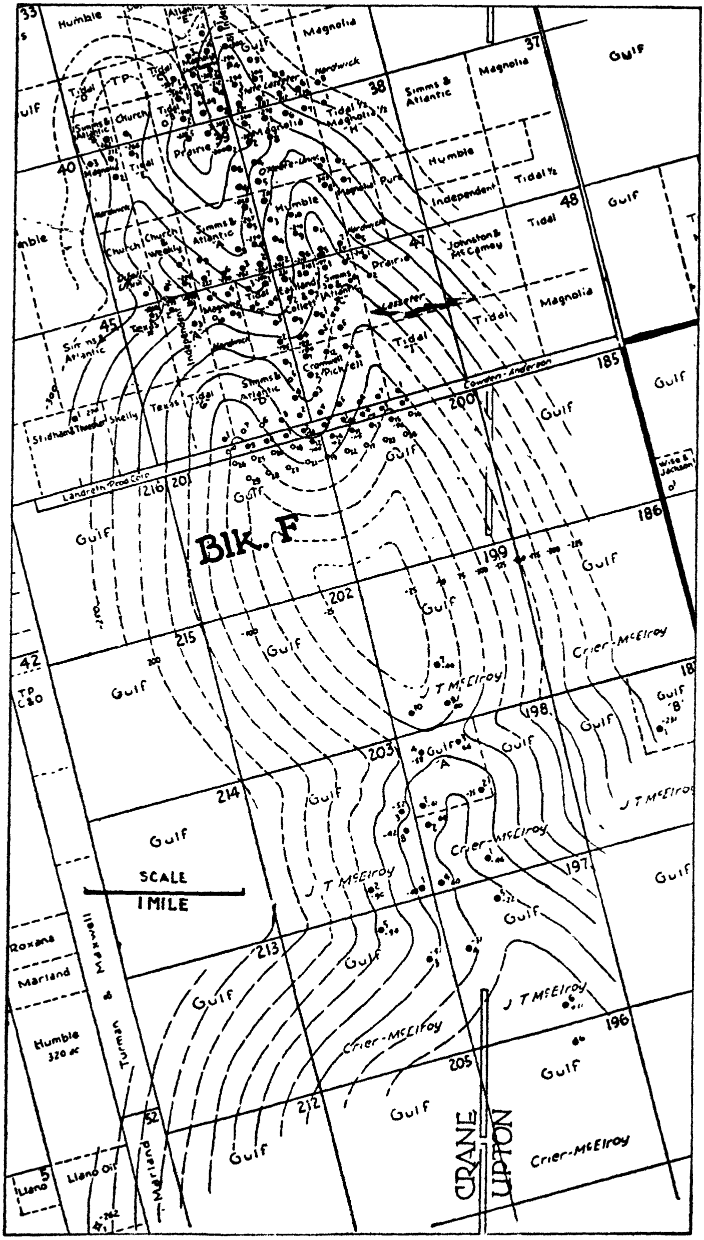

Fig. 174.—Subsurface structure-contour map of the Church and Fields-McElroy pools, Crane County, Texas. (*After Aldrich, Bull.* A.A.P.G., **11**, 1114, Fig. 2.)

salt, gypsum, and anhydrite (in the upper 2,500 feet), and massive dolomitic limestone below. In the upper portion three salt zones have been differentiated in the well logs. The first zone of salt is thickest and varies from 270 to 630 feet with an average

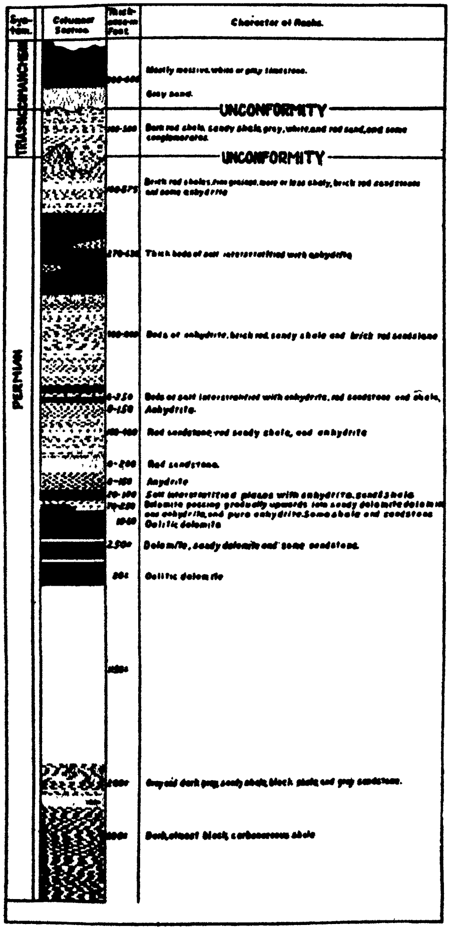

FIG. 175.—Generalized section in the Big Lake oil pool. Scale 1 inch = 1,000 feet. (*After Sellards and Patton, Bull.* A.A.P.G., **10**, 369, **Fig.** 3.)

of 500 feet. Some of this salt is red and therefore often mistaken by the driller for polyhalite. Some potash does occur in this zone, however, and there is also much anhydrite. The second salt zone is 100 feet thick, but also contains streaks of anhydrite and similar materials. As many as five salt beds occur in the

zone. The third salt zone is somewhat thicker and more readily recognized in the logs. This is succeeded by a zone in which there is much red rock, anhydrite, and sandy dolomite, grading

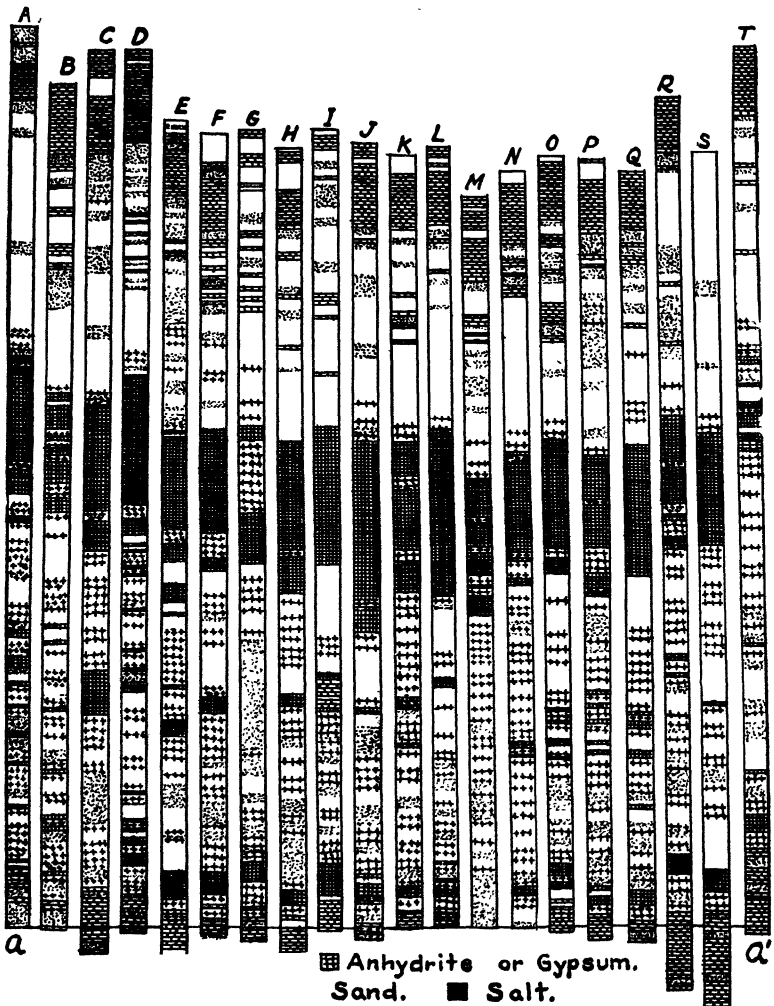

FIG. 176.—Well logs placed with the oolitic dolomite of the producing horizon as a common level. (*After Sellards and Patton, Bull.* A.A.P.G., **10**, 379, Fig. 8.)

into the Big Lime below, with no sharp line of demarkation. The top layers of the Big Lime consist of sandy limestone, calcareous sandstones, and pure dolomites. This top zone produces some

oil, but the main production comes from an oolitic horizon located about 100 feet below the third salt. The next 300 feet below the producing horizon consist again of dolomite, sandy dolomite, and sandstone in which there may be a second oolitic horizon. No information is available regarding the next succeeding layers, but in the deepest well which was drilled to a depth of 6,000 feet, the lowest 1,000 feet consist of shales a large part of which are dark, almost black and very carbonaceous. This succession is shown in Fig. 175 and the character of the upper Permian is shown in Fig. 176.

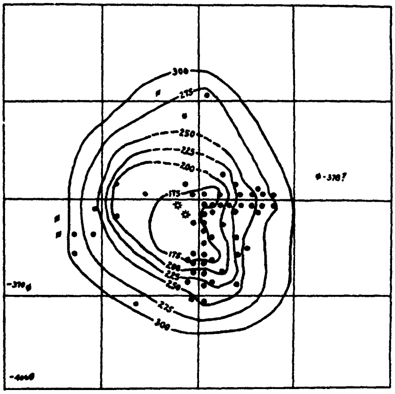

FIG. 177.—Structure map of Big Lake oil field. (*After Sellards and Patton, Bull.* A.A.P.G., **10**, 378, Fig. 7.)

The producing horizon consists of oolitic dolomite in which the individual oolites vary in size from 0.2 to 0.5 millimeter. They are concentric in structure and usually show a central nucleus, often consisting of a sand grain. The rock surrounding the oolites is quite porous and varies in chemical composition from pure limestone to pure dolomite. Figure 171, page 434 shows a photomicrograph of a portion of a well sample. Late in 1928, a deep producing horizon was found at 8,520 feet in the deepest producing well in the world.

The structure which is accountable for the production is shown in Fig. 177 which is a contour map drawn on an oolitic horizon in the producing zone. It shows a pronounced dome with a closure of over 125 feet. A map made showing the top of the middle salt gives less closure and another made showing the top of the upper salt gives very much less. This may be due to

unconformities but, more likely, is due to differential amounts of subsidence at the time each layer was forming.

The source of the oil is unknown, but the presence of a thick series of black shales below the producing horizon suggests that it may have originated in them and migrated upward. Also faults some distance away from the Big Lake field may have brought up the bituminous series and allowed migration by lateral paths. The gravity of the oil is 32.2° Bé. and the sulphur content about

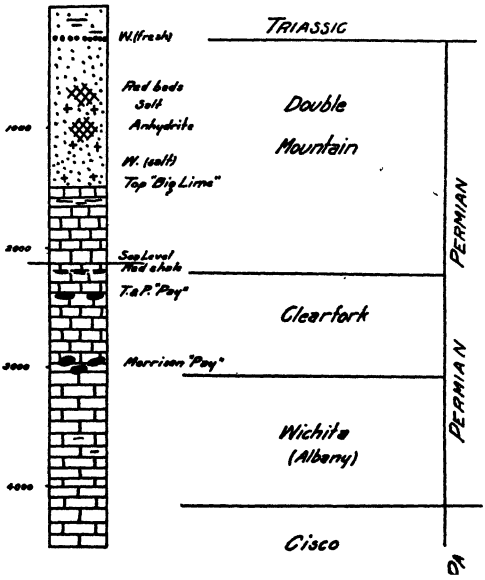

FIG. 178.—Type log for Westbrook field, Mitchell County, Texas. (*After Edwards and Orynski, Bull.* A.A.P.G., **11**, 471, Fig. 2.)

0.36 per cent. Up to the end of 1929, this pool had produced nearly 44,000,000 barrels of oil from an area of 6 square miles, or a little over 10,000 barrels per acre.

The *Westbrook* pool is located in Mitchell County on the east side of the basin. Tectonically, it appears to lie in the large syncline along the east side of the basin described on page 430. Nevertheless, the accumulation of oil in this pool is anticlinal. The pool is 7 miles long and about 2 miles wide. The first well was drilled in 1921 and produced 10 barrels from the upper pay zone at 2,498 feet in depth. A second well which went down to the deeper pay zone at 2,952 feet came in during 1921 also, at a production of 200 barrels. The Triassic strata crop out on the

surface in the Westbrook pool and show a regional dip toward the northwest. Many dry holes in this part of the province drilled on the strength of structural conditions in these Triassic rocks indicate that they are unreliable for detecting deeper structures. The red beds of the Triassic are 500 feet thick and are succeeded by the Double Mountain formation. The upper 1,000 feet of the Double Mountain is made up of red beds with some salt, gypsum, and anhydrite. Below that the Big Lime has been found for a distance of 2,200 feet. Figure 178 shows the stratigraphic section in this part of the province. The producing horizons are two in number and located 900 feet and 1,500 feet below the top of the Big Lime. The upper or 2,400-foot pay zone occurs in pores of a brownish, dense, massive limestone. The pores are small and it has been found that shooting a well will increase the flow of oil materially. The Morrison pay or 3,000-foot pay zone lies near the base of the Clear Fork portion of the Big Lime. The structure map of this pool shows a long irregular anticline with a northeast-southwest trend and about a 30-foot reverse dip. In addition to the limits imposed upon production by the structure there is also evidence that the porosity of the producing horizon becomes much smaller toward the east. The porosity is not uniform as indicated by the fact that old wells are affected differently when new offsets are drilled in. The oil is of a mixed paraffin and asphalt base with a gravity of 25.8° Bé. It contains 3½ to 4 per cent of sulphur and is capable of producing 32 per cent gasoline. The wells drilled have had an initial production of 75 barrels per day and the total recovery to the end of 1929 has been 6,931,000 barrels, while the present daily production amounts to 2,500 barrels. An interesting condition in this pool is the occurrence of non-inflammable gas in the red-bed series at depths of 1,000 to 1,300 feet. An analysis shows about 90 per cent nitrogen with 6 per cent methane, and a little ethane, with small amounts of carbon dioxide, oxygen, and helium. The origin of this gas is puzzling; it is colorless, and non-inflammable and is used in the field for power. Petroleum gas also occurs but in the same reservoir with the oil. It is a wet gas containing 4.25 to 4.75 gallons of gasoline per 1,000 cubic feet of gas.

The *Artesia* oil field is located in Eddy County, New Mexico, on the east side of the Pecos River valley centering on township 18 S. and range 28 E. It is the largest oil field in New Mexico at present. Drilling in southeastern New Mexico began in 1912,

on the C. S. Brown farm, S. 15, T. 18 S., R. 26 E., when oil was accidentally found in artesian water. This well found an oil sand at 910 feet and has produced about 20 barrels of oil ever since, together with a large quantity of water. The drilling which followed did not produce favorable results and it was 10 years later before the first commercial oil well was located in the state. The discovery well in the Artesia field was drilled in 1923 and found oil in a sandy lime formation at a depth of about 2,000 feet.

The surface formations in the Artesia field belong to the Pecos red beds and are 500 to 700 feet thick. Below these strata the Castile formation occurs, consisting of gypsum, anhydrite with interbedded sands, and red beds. The formation, 2,050 feet thick, has a very prominent key bed at a depth of 1,600 feet which consists of hard red sandstone. This bed is much used for subsurface correlation and is found in practically every well drilled in southeastern New Mexico (see Fig. 179).

Below the Castile formation lies the Big Lime, here called the San Andres formation. Although this formation is composed mostly of limestone and dolomite, in this part of the province it has green and black shales with interbedded sands near the top. The highest pay zone lies in these sands. The second pay zone lies about 150 feet lower; the third, 300 feet below the second; and the fourth 150 feet below the third.

The structure of the Artesia field is not so definitely anticlinal as is the case in the Texas pools as the normal dip is interrupted by small noses and domes. The wells in the field are scattered somewhat but are more or less bunched into three pools of 1 mile square. One of these pools has a closure of 50 feet on a dome less than 1 mile in diameter, the second is located on a smaller dome with about 25 feet closure, and the third, is located on a small plunging anticline. The total production for the year, 1929, from the Artesia field amounted to 328,200 barrels.

Production Statistics.—Since oil was discovered in the West Texas Basin province, in 1921, the various pools have produced in excess of 400,000,000 barrels. Much more could have been produced but the owners of the wells voluntarily agreed to restrict production. At the present time, the Hendricks pool in Winkler County is producing 100,000 barrels per day and practically every well in the pool is pinched in. The same is true in the Yates pool which is now flowing about 140,000 barrels per day. One well in this pool was gaged when it was brought

in at 8,528 barrels an hour which is equal to 204,000 barrels per day and there are a number of other wells which approached that figure closely. This is not an unusual condition for wells producing from limestone, inasmuch as the pores in that kind of rock are often very large. Such wells are likely to yield their production within a relatively short space of time and then

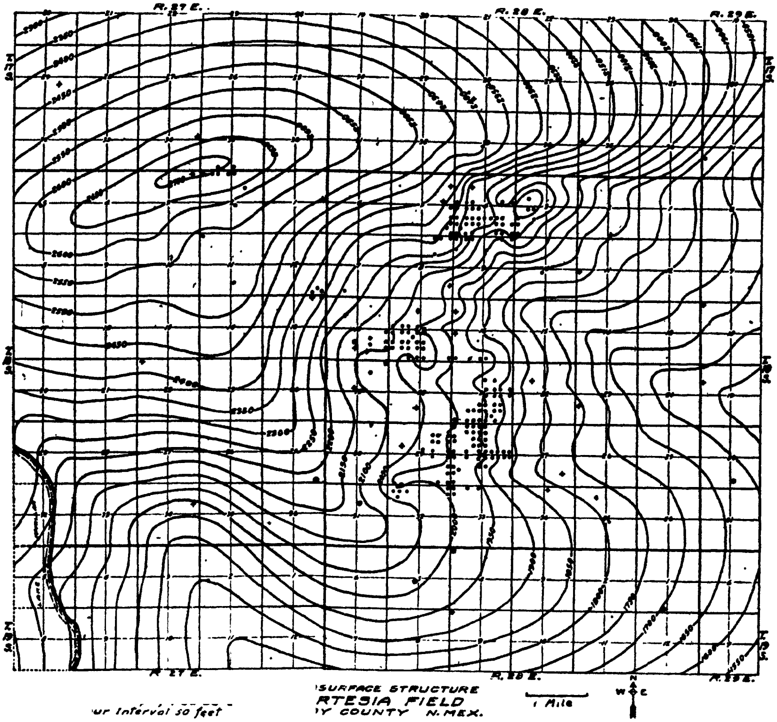

FIG. 179.—Subsurface structure of Artesia field. (*After Davis*, A.A.P.G. *Symposium*, **1**.)

go to salt water. Voluntary reduction of output is therefore a very wise precaution. The pool which has produced the most oil up to date (January, 1929) is the Hendricks with a total output of 111,000,000 barrels. It is followed closely by the Church and Fields-McCamey pool with 70,000,000 barrels and the Yates pool with 68,000,000 barrels. In time the Hendricks and the Yates pools will no doubt eclipse the rest and the total ultimate production is likely to be enormous. The gravity of the oil in the province varies from 24 to over 38° Bé., the McCamey pool

having the lower rating and the Big Lake pool the higher. The sulphur content of oil from limestone is always higher than from a quartz sand. In these pools it seems to be unusually high, a large number running above 2 per cent. The lowest in this respect is the Big Lake pool in which the sulphur content is 0.36 per cent. Most of the crudes are rated as intermediate in base by the Bureau of Mines. The two exceptions are the Hendricks and the Yates crudes which are rated as napthene base.

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CHAPTER X

THE ROCKY MOUNTAIN GEOSYNCLINE PROVINCE

Leaving the central part of the United States and proceeding westward, the largest petroliferous province on the continent is encountered. It includes oil and gas pools and fields in New Mexico, Colorado, Utah, Wyoming, and Montana, all of which have certain features in common which make it necessary to include them in the same province. The Rocky Mountain geosynclinal basin originally formed a part of the Cordilleran geosynclinal basin and occupied most of the states of Montana, Wyoming, and Colorado besides portions of eastern Utah and northern New Mexico. The Cordilleran geosyncline with its extensions covered a vast area reaching from the old land masses of Laurentia, Ozarkia, and Llanoria on the east to Monzonia on the west (see Fig. 5). Monzonia extended from Canada through western Idaho, western Nevada, southeastern California to Mexico, lying chiefly between 114 and 118° longitude. It is so called because it consists largely of monzonite or related kinds of igneous rocks.

According to Schuchert, the Cordilleran geosyncline was probably in existence during Proterozoic time and probably in the same position and with the same areal extent as during the Paleozoic era. This is indicated by the distribution of the *Proterozoic Belt series* which has been traced from southern Arizona into British Columbia as far as latitude 55° north. A condition which seems remarkable in the light of world events elsewhere is the fact that the Proterozoic and Paleozoic rocks are so nearly conformable. The great thickness of the Paleozoic rocks in the geosyncline attests to a very prolonged existence free from major disturbances. This applies particularly to the early part of the era; namely, the Cambrian, Ozarkian, and Canadian periods. Sediments of Paleozoic periods are thickest in the south and reach a total of, approximately, 28,000 feet in the Inyo Range of southeastern California. The Cambrian, Ozarkian, and Canadian sediments alone have a thickness of 17,000 feet in that range.

By the end of Canadian time, there is evidence of the culmination of the quiet periods of deposition and diastrophic movements began in various parts of the geosyncline. The Ordovician, and especially the Silurian and Devonian, rocks are missing over great areas in the region covered by the geosyncline. Such hiatuses in various parts of the section show that movements were taking place on a large scale and probably in many parts of the area. The movements reached their first culmination by the close of Jurassic time when the great Cordilleran Intermontane geânticline became very clearly defined. In succeeding Cretaceous time there were two basins of deposition. On the west side lay the Pacific geosyncline with a length of 2,500 miles and, on the east, the Rocky Mountain geosyncline which extended in a sigmoid curve from Bering Straits, through Canada, to the Great Plains of the United States, and south to the Caribbean sea—a total distance of 5,000 miles.

All the oil and gas fields discovered in the area of the Cordilleran geosyncline except those in California are located in the eastern successor of this huge trough, the Rocky Mountain geosyncline. Its western border was located in Idaho, western Utah, and eastern Arizona along the barrier called, by Ransome, the "Cordilleran Intermontane Belt." The eastern border does not concern us at present inasmuch as all the fields are close to the western border. Throughout Comanchean and Cretaceous times sedimentation was in progress, but at the end of the Cretaceous period the Laramide revolution brought about a cessation of deposition. The Paleozoic and Mesozoic strata were greatly deformed and thrown into anticlines and domes from the Canadian border south into New Mexico. Faulting on a grand scale accompanied the folding, and the large overthrust faults described from Montana, Wyoming, and Colorado no doubt began their development at this time. Volcanic activity was pronounced and the western portion of the geosyncline especially was affected by intrusions in the form of batholiths and laccoliths as well as by extrusions of lava flows and volcanic ejectamenta.

These disturbed conditions continued well into the Tertiary period and perhaps reached their culmination during the Pliocene epoch of that period. There is evidence of overthrusting during the Eocene epoch as well as much evidence of volcanic activity. The temporary lakes which came into existence during the Tertiary were the site of particular kinds of sediment and they now

occupy a large portion of the area in which the oil and gas fields occur.

Tectonics.—With the above facts in mind we are ready to examine the tectonic setting of the oil fields in the Rocky Mountain

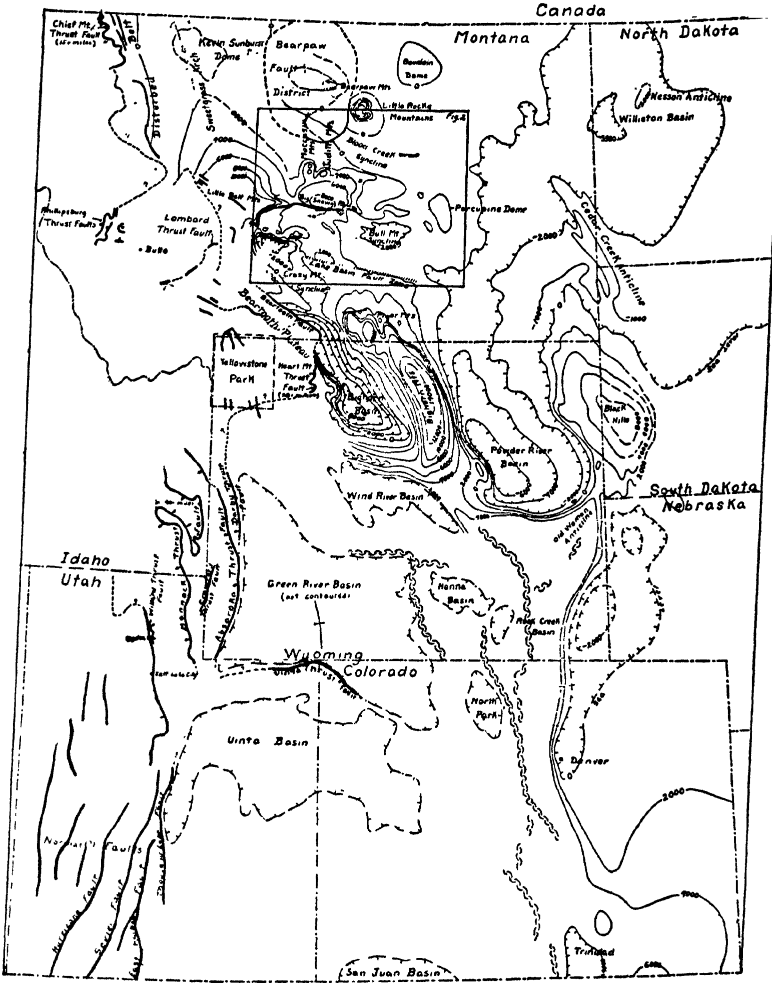

FIG. 180.—Structural sketch map showing the main tectonic elements in the Rocky Mountain petroliferous province. (*After Thom, Bull.* A.A.P.G., 7, 3.)

tain Geosyncline province. These fields appear in a relatively narrow belt running nearly north and south from central Montana through the entire width of Wyoming, through western and central Colorado, eastern Utah and into northwestern New

Mexico. The most prolific fields and the greatest number of pools are located in Wyoming, while the next in importance lie in Montana, those in the other three states being of lesser importance. Figure 180 shows the tectonic elements in the greater part of the province. It will be noted that the western side of the province is characterized by overthrust faults beginning with the Chief Mountain thrust in northwestern Montana. Continuing south, the Phillipsburg and Lombard faults lead on to the Heart Mountain thrust in northwestern Wyoming, which in turn gives way to a zone of faults in southwestern Wyoming and southeastern Idaho of which the Bannock and Absaroka thrusts are the best known. These are succeeded by another zone of faults in eastern Utah. The continuous linear character of the Canadian Front range which is composed of the Paleozoic strata, faulted and overthrust eastward, breaks up into a number of minor ranges in Montana and suffers still further dispersion in Wyoming. The narrow belt of intensely faulted and folded rocks, which separates the Canadian Front Range from the great plains to the east, is broken up in Montana by a series of local uplifts and detached short ranges, occupying a rather wide belt which widens until the southern line of Wyoming is reached, where it again takes on the continuous linear character, but here probably representing rocks deformed at a different period. It is this intermediate belt which is of the most interest, for many of the important oil fields are located within its confines. In Montana, a prominent tectonic element in the belt is called the "Sweetgrass arch," another is indicated in the figure by the nearly east-west line of deformation centering on the Big Snowy Mountains and therefore called "Big Snowy anticlinorium." In Wyoming, the Big Horn Mountains stand out most prominently with the Big Horn basin to the west and the Powder River basin to the east, separating the Big Horns from the Black Hills. In the southwestern part of Wyoming lies the Green River basin which has the Medicine Bow Mountains on the east and the fault zone on the west. In the southeastern part of Wyoming is the Laramie range with a prong pointing toward the Black Hills. In northwestern Colorado lies the Uinta basin reaching over into Utah. In southwestern Colorado lies a part of the San Juan basin. In succeeding pages it will be seen that all these major tectonic elements have a bearing on the location of the oil fields of the province.

Stratigraphy.—The succession of rocks in the Rocky Mountain geosyncline province includes formations belonging to nearly every system from the oldest Paleozoic to the youngest Cenozoic groups. The Quaternary is represented by alluvium, terrace gravels, and volcanic materials. The Tertiary system is particularly in evidence, because of its thickness and wide extent. Thicknesses of 8,000 feet or more are common for rocks of this part of the geologic section. The underlying Cretaceous rocks,

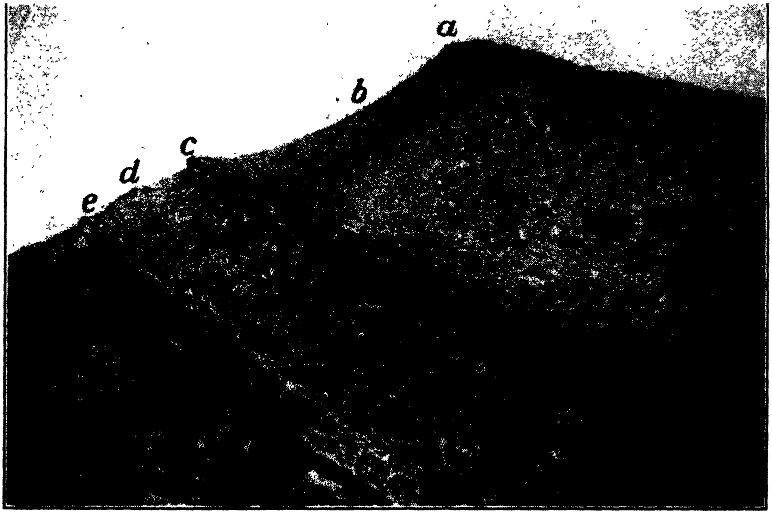

FIG. 181.—North wall of Soldier Canyon near Loveland, Colo. Showing the lower sandstone (*e*), 36 feet thick; the variegated lower shale (*d*), 32 feet thick (for scale note the horses on the slope); the middle sandstone (*c*), 12 feet thick; the middle shale (*b*), 234 feet thick; and the upper sandstone (*a*), 41 feet thick. (*After Lee, U. S. Geol. Survey Bull.* 751.)

however, are the most important, for in them the best reservoir sands have been found. They also are very thick, exceeding 10,000 feet in Wyoming without taking into account transition rocks between the two systems. Because different sets of names have been used for them in various parts of the province, it is not a simple matter to correlate them from point to point. Fortunately, the basal sandstone was laid down over nearly the whole area and therefore becomes a most helpful key horizon. Figure 181 is a typical picture of the Dakota sandstone according to the interpretation of Lee who devoted considerable time and thought to its proper correlation throughout the province. It will be seen to consist of three prominent sandstone members separated

by two shale zones. The lower sandstone is 36 feet thick, the middle one 12 feet, and the upper one 41 feet thick. Perhaps it should be pointed out that this tripartite division is not accepted by all geologists and does not conform to the usage of a decade ago. Previous to Lee's work only the lower and middle sandstones were regarded as constituting the Dakota formation; the upper one being placed in the lower part of the

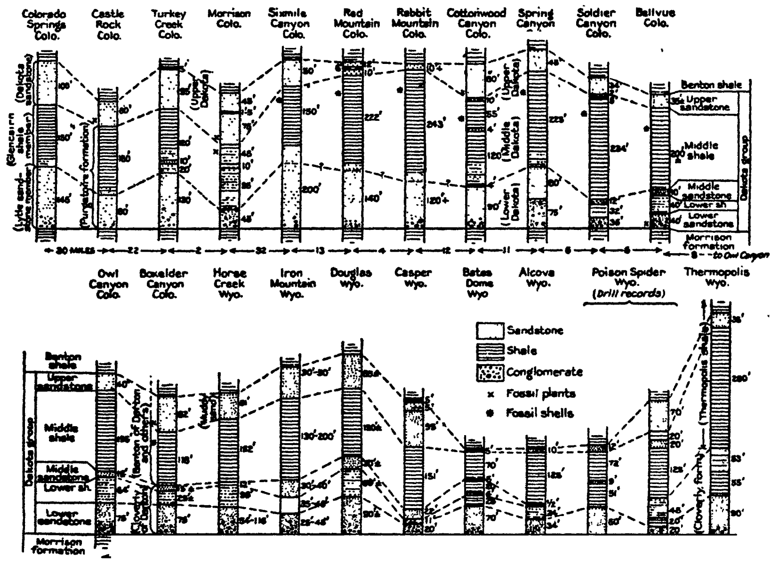

FIG. 182.—Correlation of the Dakota sandstone members between Colorado Springs, Colo., and Casper, Wyo. (*After Lee, U. S. Geol. Survey Bull.* 751.)

Thermopolis formation. On account of the fact that the Dakota is the most important and omnipresent oil horizon in the province, and that its stratigraphic position and general character will bear emphasis, Fig. 182 has been inserted; this figure bringing out clearly the thickness, lithology, and former nomenclature of the formation. The lowest sandstone, sometimes called the "Lakota" is a part of the *Cloverly* of Wyoming, while the middle sandstone is the one which has been called the "Dakota" by most writers and will probably continue to be the typical Dakota for some time. Nevertheless, the fact that the uppermost sandstone is very widespread and as a rule more uniform than the middle sandstone, makes Lee's grouping of the sandstones seem more practical than the former twofold grouping.

A somewhat startling fact brought out by Lee's studies is that of the crustal movements of the Laramide revolution which took place at the end of the Cretaceous period, involving displacements of over 10,000 feet. This is shown in diagrammatic form in Fig. 183, which is an ideal cross-section across the Rocky Mountains, showing the original position of the sandstone before the diastrophic movements took place.

Beneath the Cretaceous rocks, Comanchean, Jurassic, and Triassic are found. They lie above Permian, Pennsylvanian, and Mississippian strata. The Devonian and Silurian strata *are missing* in the oil-producing districts. Rocks of Ordovician and Cambrian age are present, however, but not very thick. All systems will be more fully described in succeeding pages.

Producing Horizons.—In order to give comparisons of the producing horizons in the different parts of the province, the table on page 455 is inserted.

The youngest important producing horizon in this province is the sandstone found about the middle of the Steele formation in Montana and Wyoming. It is quite commonly considered the base of the Montana series in Montana, but occurs some distance above the base in Wyoming. The Eagle of Montana cannot be traced down to a point in Wyoming where the Shannon is typically developed. It is believed, however, that they both occur at about the same stratigraphic level. In

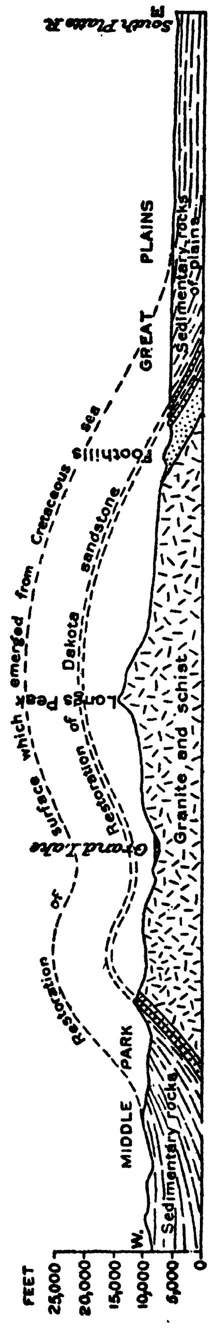

FIG. 183.—East-west profile across the Rocky Mountains showing the original position of the Dakota sandstone and the amount of deformation which it has suffered. (*After Lee, U. S. Geol. Survey Bull.* 751.)

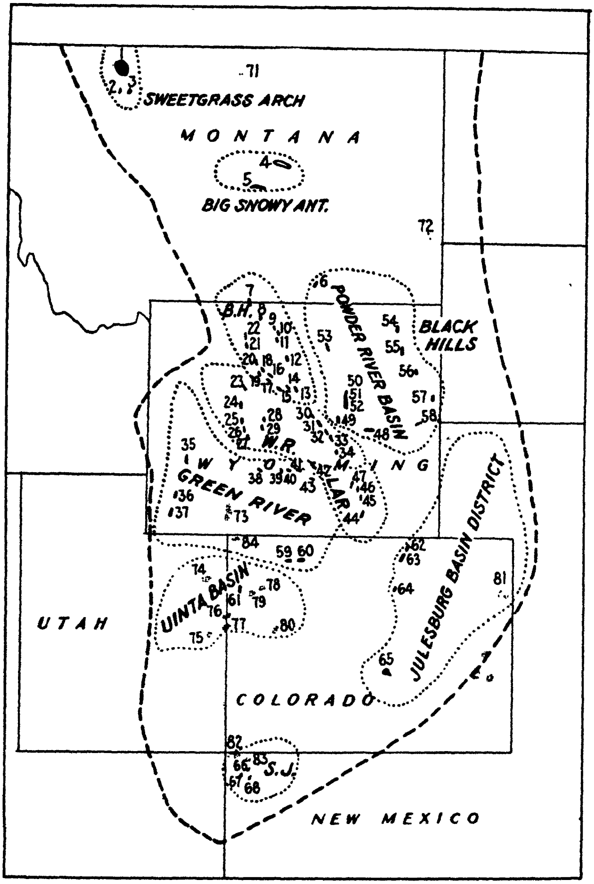

FIG. 184.—The Rocky Mountain petroliferous province. Districts in the province outlined by dots. Oil pools shown in solid black. Gas pools shown by stippled areas. Nos. 1 to 68 are oil pools and Nos. 71 to 83 gas pools, as follows:

OIL POOLS

1. Kevin-Sunburst
2. Pondera
3. Banatyne
4. Cat Creek
5. Devils basin
6. Soap Creek
7. Elk basin
8. Byron
9. Greybull
10. Lamb
11. Torchlight
12. Hidden dome
13. Black Mountain
14. Kirby Creek
15. Warm Springs
16. Golden Eagle
17. Hamilton dome
18. Grass Creek
19. Enos Greek
20. Buffalo basin

OIL POOLS

21. Oregon basin
22. North Oregon basin
23. Maverick
24. Pilot Butte
25. Hudson
26. Dallas
27. Derby
28. Alkali
29. Sand Draw
30. Arminto
31. Boone dome
32. Poison Spider
33. Iron Creek
34. Bolton Creek
35. Big Piney
36. La Barge
37. Spring valley
38. Little Buffalo
39. Lost Soldier
40. Werts

OIL POOLS

41. Mahoney
42. Ferris
43. G. P. dome
44. Rex Lake
45. Rock Creek
46. Medicine Bow
47. Simpson ridge
48. Big Muddy
49. North Casper
50. Shannon
51. Salt Creek
52. Teapot
53. Billey Creek
54. Moorecroft
55. Upton-Thornton
56. Osage
57. Mule Creek
58. Lance Creek.
59. Iles
60. Moffat

TABLE OF PRODUCTIVE HORIZONS IN ROCKY MOUNTAIN PROVINCE

System	Formation	Montana	Wyoming	Colorado	New Mexico	Utah
Cretaceous	Steele	Eagle	Shannon			
	Pierre			Shale		
	*Frontier		Wall Creek			
	Mowry		Sands			
	Mancos			Shale		
	**Dakota	Cat Creek	Muddy Dakota Greybull	Muddy Dakota	Dakota	Dakota
Comanche	Cloverly	Sunburst Second Cat Creek	Lakota			
Jurassic	Sundance	Ellis	Sundance	Sundance		
Permian	Embar		Embar			
Pennsylvanian	Tensleep	Quadrant	Tensleep		Tensleep(?)	Hermosa Goodrich
Mississippian	Madison	Madison				

Wyoming, oil is found in the Shannon in the Salt Creek pool. In Montana, only gas is found in the Eagle sand. Some production in a series of thin sands which lie about at the same horizon as the Eagle and the Shannon is found in southwestern Wyoming in the Hilliard formation. The production is not large. Each horizon will be described in connection with the districts in which it is important.

Districts.—In the Rocky Mountain petroliferous province, there are ten districts in which the production has been great enough to warrant separate treatment. Two of these are in Montana; the Sweetgrass arch and the Big Snowy anticlinorium. Five lie wholly or partly in Wyoming; namely, the Big Horn, Wind River, Green River, Laramie, and Powder River basins. The Big Horn basin extends a short distance into Montana and one field—the Elk Basin, lies in both states. The Green River basin reaches over into northwestern Colorado and northeastern Utah. In Colorado there are three districts; the eastern or Julesburg

OIL POOLS

61. Rangely
62. Wellington
63. Ft. Collins
64. Boulder
65. Cañon City
66. Hogback
67. Rattlesnake
68. Table Mesa

GAS POOLS

71. Havre
72. Gas City, Cabin Creek and Baker
73. Baxter basin (Rock Springs)
74. Ashley
75. Cisco
76. Carbonera

GAS POOLS

77. Garmesa
78. Thornburg
79. White River
80. De Beque
81. Wray
82. Ute dome
83. Aztec
84. Hiawatha

basin, a small portion of the Green River basin, and a part of the Uinta basin. The last named also reaches over into eastern Utah. Finally, the tenth district lies mostly in northwestern New Mexico and is called the "San Juan Basin district." Instead of describing these districts individually the oil pools in them will be described by states in this volume, but because the districts are tectonic units, they will form the basis of classifying the pools into groups within the states.

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WYOMING

From the standpoint of total production Wyoming ranks first in the Rocky Mountain petroliferous province. The Salt Creek field (in Natrona County) has produced the greatest amount of oil. For the year, 1928, its production was 11,365,000 barrels and the total up to date has exceeded 200,000,000. Furthermore, it is estimated that the field will have a total ultimate production

of close to 500,000,000 barrels. Grass Creek, with a total production of 20,000,000 barrels, at the end of 1929, ranks second and Big Muddy, with 19,000,000 to its credit, ranks third. Other important fields are Lost Soldier, Rock Creek, Hamilton, Elk Basin, Lance Creek, Poison Spider, Teapot Dome, Mule Creek, Osage, La Barge, and Hudson. Each of these fields has produced more than 100,000 barrels during the past year (1929).

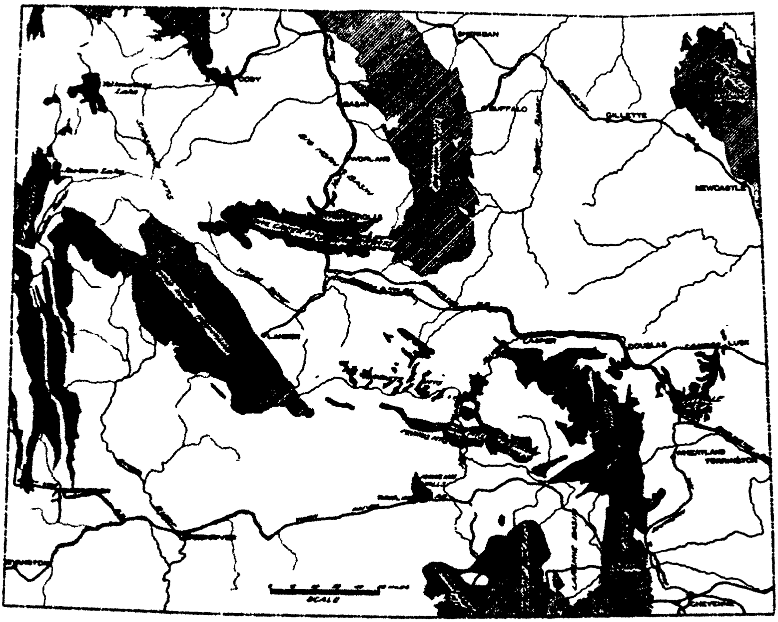

FIG. 185.—Major uplifts of Wyoming as shown by outcrops of Dakota and older rocks. (*After Ball, Bull.* A.A.P.G., **5**, 50, Pl. I.)

The state of Wyoming and its oil fields may be divided very conveniently into districts on a tectonic basis. It will be seen presently that all the fields have a tendency to occur close to the border of a structural basin which in Wyoming is likely also to be a topographic one. These basins have received local names and such names will be used in this discussion. Five basins may be defined; namely (beginning in the northeast part of the state), the Powder River, Big Horn and Wind River basins in the center; the Green River basin in the southwestern part; and the Laramie basin in the southeastern part of the state. There are 10 fields, or pools, in the Powder River basin, 15 pools in the Big Horn

basin, 13 pools in the Wind River basin, 11 in the Green River basin, and 4 in the Laramie basin, all of which are now or have in the past produced commercial quantities of oil and gas. Besides these there are numerous other anticlines and domes which have been mapped and described and it is to be expected that some of them may become producers in the future.

Tectonics.—The tectonic elements in the state of Wyoming can be seen at a glance by examining Fig. 180, page 449. The following positive elements will be noted; Black Hills, Big Horn, Owl, Bridger, and Wind River Mountains; Ferris, Seminole, Freezeout, and Laramie Mountains and Medicine Bow range. Most of these consist of old crystalline rocks, granite, gneiss, and metamorphic, either at or close to the surface under a cover of sedimentary rocks. They are a part of the old basement complex faulted up, and through the overlying strata; and in some cases possibly batholithic masses pushed up into Paleozoic and Mesozoic strata. Between these positive elements lie the basins just enumerated. They are real structural basins in which the sedimentary rocks are thousands of feet thick and where the pre-Cambrian lies buried at great depth. The center of the basins is usually occupied by young Tertiary and the periphery by older Cretaceous or Comanchean strata, as a general rule. The basins are huge synclinoria in which smaller anticlines and synclines are superposed upon the larger pattern. Inasmuch as most of these minor structures were produced at the time of the Laramide revolution, that is, at the end of the Cretaceous period, they only show up prominently around the borders of the basins, because toward the center they are hidden by the blanket of younger rocks. A good illustration of this is shown in Fig. 184, page 454, where the anticlines surrounding the Big Horn basin are seen.

In some cases it is apparent that the anticlines may be thought of as occurring on the saddle between two major positive elements as, for instance, in the case shown in Fig. 186. This shows the Emigrant Gap and a few other anticlines as extending across the gap between the Laramie and the Big Horn Mountain uplifts. Such folds are called "axial upfolds" by Ball[1] who has described the tectonics of Wyoming in a very lucid manner. In the first type, which he calls "basin upfolds," he distinguishes two kinds according to the inclination of the limbs of the fold. The more

[1] BALL, MAX (see Bibliography).

common kind of anticline has both limbs of nearly equal steepness, or else the steeper side toward the nearest major tectonic element. The exceptional kind has the gentle dip toward the nearest major tectonic element and the steeper dip toward the center of the basin.

Ball also cites evidence to show that some of the minor anticlines and domes were affected by diastrophic movements during

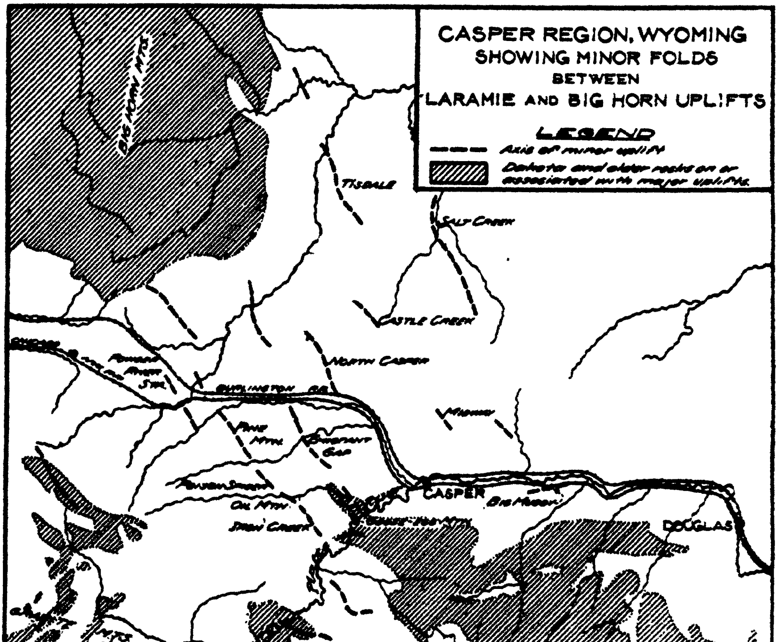

FIG. 186.—Casper region, Wyoming, showing minor folds between Laramie and Big Horn uplifts. (*After Ball, Bull.* A.A.P.G., **5**, 52, Pl. II.)

Eocene time. Often the early Eocene sediments are seen to lie conformably upon the Cretaceous, but are separated from the Wasatch, or later Eocene strata by a considerable unconformity. He also mentions two cases in which folding took place even later, that is, in Wasatch time. The Buffalo Basin dome in southeastern Fremont County shows basal Wasatch beds tilted at angles (up to 30 degrees), but the underlying beds are tilted even more and the discordance of dip amounts to from 0 to 32 degrees. Another fold which has the Wasatch beds folded is Simpson's

Ridge located in east-central Carbon County near Rock Creek and Medicine Bow pools. There the Wasatch or its equivalent lies at angles of from 1 to 60 degrees which is less than the underlying sedimentaries by 5 to 40 degrees. On the south end of the Freezeout Mountains, one of the major tectonic elements, the Wasatch strata stand vertical or are overturned in accordance with the older beds.

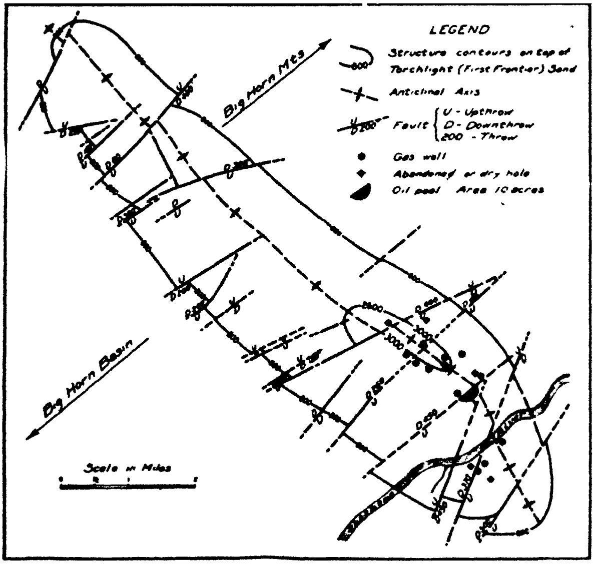

FIG. 187.—Garland anticline, Park and Big Horn counties, Wyo. (*After Irwin, Bull.* A.A.P.G., **11**, 119, Fig. 4.)

Besides being characterized by their height and great closure, the anticlines and domes of Wyoming are also characterized by faults. Unfaulted upfolds are rare, and those which have been described without faults either have soft, more or less unconsolidated strata, as a covering to obscure faulting, or have not been observed closely enough. The faults may be present as a system in which the faults are parallel to each other or they may be present as a system with a radial pattern. Such faults which occur on or in close association with anticlines were named "epi-anticlinal" faults by Pratt.[1] In Wyoming, these faults seem to be decidedly local phenomena and not regional as has been thought by some geologists. They appear to be confined to the uplift

[1] *Bull.* A.A.P.G., **7**, (No. 3), 243, 1922.

and the immediately surrounding territory. Perhaps the best illustration of this fact is the geologic map of the Baxter Basin or Rock Springs area prepared by Schultz[1] which shows that the faults die out at the edge of the uplifted area. Estabrook, describing the faults of the Salt Creek dome, states that they diminish rapidly in magnitude from the axis of the anticline outward. Another peculiarity of these faults, which was ascertained

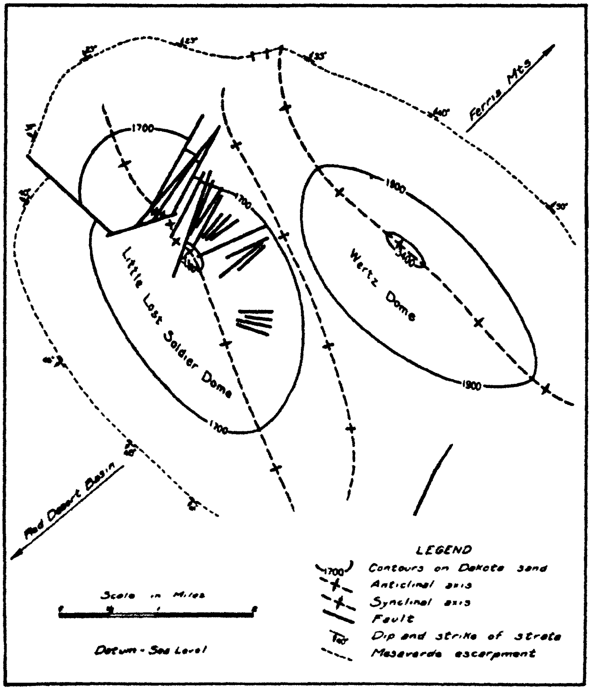

FIG. 188.—Little Lost Soldier and Wertz domes, Carbon County, Wyo. (*After Irwin, Bull.* A.A.P.G., **11**, 120, Fig. 5.)

when a careful study of subsurface conditions in the Teapot dome was undertaken, is the fact that they show up prominently in the massive beds (chiefly the thick sandstones), but are absent or small in the shales. Apparently the yielding nature of the shales takes up the displacement due to faulting, whereas the more unyielding sandstones preserve the displacement. Faults which show on the surface, therefore, do not extend down directly, but are offset in successive sandstones on the way down.

[1] *U. S. Geol. Survey Bull.* 702, map in pocket.

Figure 187 illustrates the parallel type of systematic arrangement of epi-anticlinal faults. There are 24 transverse faults and one axial fault shown in this illustration. On the Salt Creek anticline 20 transverse faults are mapped and on the Baxter Basin anticline the number is 50. On some domes, as stated above, the arrangement of the faults is radial rather than transverse. This is shown in Fig. 188 which reveals a radial type of faulting on the Little Lost Soldier dome. The absence of faults on the Wertz dome is not due to lack of faults but rather to the difficulty of mapping them on account of the extensive cover of non-resistant beds. Irwin[1] who describes faulting in the Rocky Mountain region in considerable detail, believes that these epi-anticlinal faults are probably due to tension developed contemporaneously with folding. Link[2] performed experiments to test out the theory and believes that his findings bear out the correctness of the assumption. Furthermore, he finds that on long anticlines the tendency is to form fissures parallel to each other and that on essentially circular domes the fissures have a radial pattern.

From actual observation and study of well logs it has been found that epi-anticlinal faults have a vertical displacement varying from 5 to 700 feet and may extend in depth to 3,000 feet. Relatively elevated or depressed blocks, horsts, and grabens are quite common. Transverse segments of folds are often shifted along the trend of the faults resulting in an offset of the axis of an anticline. Such strike slip is illustrated in the Garland and the Little Lost Soldier anticlines shown in Figs. 187 and 188. Occasionally, scissors faults are found in which the downthrow at one end passes through a zero center to an upthrow at the other end. The thrust faults of Montana have been interpreted by Frank Reeves as gradually flattening and merging with the bedding plane.[3]

Stratigraphy.—The following correlation table will enable the reader to become acquainted with the nomenclature used in the five different oil districts of Wyoming:[4]

[1] *Bull.* A.A.P.G., **11**, 105–130, 1927.

[2] LINK (see Bibliography).

[3] See Bibliography, Highwood Mountains, Montana.

[4] In the correlation table the following authorities were followed; Big Horn Basin, *U. S. Geol. Survey Bull.* 656; Wind River Basin, *Bull.* 702, p. 36, *Bull.* 641, p. 238; Green River Basin, *Bull.* 796, p. 175, and *Bull.* 702, p. 24; Laramie Basin, *Bull.* 702, p.36 and 806, p. 134; Powder River Basin, *Bull.* 736, p. 76 (table).

		Big Horn basin	Feet	Wind River basin	Feet	Green River basin	Feet	Laramie basin	Feet	Powder River basin	Feet
Tertiary				White River	0 to 1,500	Bishop	2,000				
	Eocene					Bridger	2,000				
						Green River	1,500				
		Wasatch	1,300	Wind River	0 to 2,900	Wasatch	2,000	Hanna			
		Fort Union	2,000 to 5,600	Fort Union		Post-Laramie	6,000 to 9,000			Fort Union	
Cretaceous		Lance	1,500	Lance		Laramie	1,500			Lance	
	Montana	Meteetse		Lewis		Lewis	680	Lewis	2,500		
		Mesaverde		Mesaverde	300	Mesaverde	1,800	Mesaverde	1,250	Fox Hills	50
				Steele		Steele		Steele	3,300	Pierre	1,250
		Cody	2,000	Niobrara	3,500	Niobrara	6,100	Niobrara	700	Niobrara	200
				Carlile		Carlile		Carlile	460	Carlile	610
	Colorado									Greenhorn	100
		Frontier	500	Frontier	900	Frontier	700	Frontier	700		
		Mowry	300	Mowry	260	Mowry	120	Mowry	120		
										Graneros	1,000
		Thermopolis		Thermopolis	300	Thermopolis		Thermopolis	140		
				Dakota		Dakota				Dakota	75
Comanche		Cloverly	200	Cloverly	150			Cloverly	125	Fuson	30
										Lakota	200
		Morrison	400	Morrison	300	Morrison	250	Morrison	225	Morrison	150
Jurassic		Sundance	400	Sundance	200	Sundance	700	Sundance	350	Sundance	350
Triassic		Chugwater	800	Chugwater	1,300	Chugwater	985	Chugwater	1,350	Spearfish	500
				Dinwoody	150						
Permian		Embar	350			Embar	260	Forelle limestone		Minnekahta	40
				Park City	200			Satanka	140	Opeche	75
Pennsylvanian		Tensleep	150	Tensleep	400	Tensleep		Casper	1,000	Minnelusa	600
		Amsden	175	Amsden	200	Amsden	180				
Mississippian		Madison	800	Madison	500	Madison	300			Pahasapa	700

It will be noted that there is a very general uniformity in the use of names for the formations exposed within the oil-bearing portions of the state of Wyoming. The Green River basin shows the thickest section of Tertiary rocks. Sandstones, shales, thin limestones, and coal constitute the kinds of rock which characterize the Tertiary. They have little importance in connection with the oil deposits of the state except that many seepages have been found in them (especially in the Wind River basin). Such seepages of oil or gas, however, merely indicate leakage from some lower horizon in the Cretaceous or older rocks and probably do not indicate that any considerable amounts of either will ever be found in Tertiary rocks.

The Cretaceous rocks may be subdivided into four series with the Laramie at the top and the Dakota at the base: The *Laramie* consists of shaly sandstone, dark shale, and a little coal; the *Montana* consists chiefly of shales with some sandstones interbedded and considerable coal near the middle of the series; the *Colorado* also consists chiefly of shale. In this case, much of the shale is black and fissile, especially in the Mowry formation. A very important sandstone horizon occurs in this series called the "Frontier." It is not a single body of sandstone, but is broken up into many units by shale partings. The prolific Wall Creek sands of the Salt Creek and Big Muddy fields lie partly within the Frontier formation. In the Big Horn basin much of the oil occurs in one or several sands within the Frontier formation.

At the base of the Cretaceous lies the *Dakota sandstone,* sometimes differentiated from the Comanchean below[1] and sometimes classed with it as the Cloverly formation. It produces oil also, but is not as prolific as the Frontier Sandstone zone. The Morrison beds, which are now quite generally considered to be of Comanchean age, consist of purple, green, and grey shales with sandstones interbedded. The Sundance of Jurassic age is interesting because some oil has been found in it in the Powder River basin and the eastern part of the Green River basin. It consists of clastic materials, sand, clay, marl, etc., and is a marine formation. The thickness varies from 85 to 700 feet in various parts of the state. Red shale, sandstone, and gypsum make up the succeeding formation of the Chugwater. It is considerably thicker than the Sundance and averages close to 1,000 feet in the oil fields of the state. In the Lander field it produces some

[1] Consult *U. S. Geol. Survey Prof. Paper* 149.

oil which seems rather remarkable, considering its makeup and position in the section and is probably, in part, of Permian age.

The remaining Carboniferous formations, the Embar, Tensleep, Amsden, and Madison, are all important. Two of them are now producing commercial quantities of oil and one of the other two is a producing horizon in Montana. It is quite conceivable that future and deeper drilling on proved structures will show that each one carries oil and gas. The *Embar* formation includes a series of marine deposits consisting of grey limestones and chert beds with some shale and in places some gypsum. Its range in thickness is from 250 to 480 feet. In the Wind River basin, Blackwelder has divided this formation into two units; the *Dinwoody* and the *Park City*. It is also an oil horizon. In the Powder River basin, Darton's names, first used in the Black Hills, are chosen for the generalized section.

The *Tensleep* sandstone is one of the deep horizons looked upon with favor by the oil geologists. It overlies the Amsden conformably and consists of white to grey, massive, and cross-bedded sandstone. In places limestones are intercalated with the sandstones. It varies from 30 to 400 feet in thickness and is a splendid aquifer. The underlying Amsden formation comprises limestone shale and chert. In the Big Horn basin the lowest 60 to 80 feet consist of bright red shale with thin layers of limestone and chert. The *Madison limestone* of Mississippian age is the lowest formation which has any attraction for the petroleum engineer. It is a very massive, grey limestone ranging in thickness from 600 to over 1,000 feet. The lower part is more sandy than the upper part.

Beneath the Madison limestone some strata with Devonian and possibly Silurian fossils have been found in western Wyoming west of the oil-producing area. These strata are limestones for the most part and rather thin. Under them the Ordovician *Big Horn limestone* and Cambrian *Deadwood sandstone* crop out in a few places. They are well known in the Big Horn basin and in the eastern part of the Powder River basin. The Big Horn formation varies from 150 to about 300 feet and consists of siliceous grey limestone often dolomitic. The Deadwood formation consists of sandstone, shale, and conglomerate and varies in thickness from about 700 to 900 feet. Neither of these formations appear to have any oil possibilities.

Producing Horizons.—There are at least 12 producing horizons in the oil and gas fields of Wyoming. They extend from the Steele formation in the Montana series down to and including the Pennsylvanian Tensleep formation. The most prolific zone is the series of sands in the Frontier formation called by various names in different parts of the state. Below the Frontier sands, the Dakota, Lakota, Sundance, Embar, and Tensleep are the most important producing horizons. In the following table all

TABLE OF PRODUCING HORIZONS IN WYOMING

Formation	Sands	Where productive by districts[1]				
		Big Horn basin	Wind River basin	Green River basin	Laramie basin	Powder River
Steele	Shannon		Boone (gas) Pilot Butte		Simpson Ridge	X
Hilliard	Sands			X		
**Frontier	*First Wall Creek			Big Buffalo		X
	*Second Wall Creek			Baxter basin		X
	Third Wall Creek	Enos Creek	Arminto	Big Buffalo		X
	*Frontier	X	Boone and others	Lost Soldier	Medicine Bow	X
	Och-Louie	Torchlight				
	Peay	Torchlight and Lamb				
Mowry	Sands			Ferris and Lost Soldier		Osage
**Dakota	Dakota			X	X	Lance Creek
	*Greybull	X				
*Lakota	*Lakota			Wertz (gas)	X	X
Morrison	Morrison	Grass Creek				
*Sundance	*Sundance		X	Lost Soldier		Salt Creek
Chugwater	Chugwater		Bolton			
*Embar	*Embar	X	X			
*Tensleep	*Tensleep	Greybull and Grass Creek	Notches	Mahoney Dome		North Casper Salt Creek
Madison		Frannie				

[1] X indicates that the sand is productive in more than one pool. Otherwise the name of the pool is given. A star before the name of a formation or sand means that it is more important than the formations or sands not so starred. The most important have a doublestar.

sands are listed in stratigraphic order with the corresponding geologic formation name and the parts of the state where the sands are productive.

BIG HORN BASIN DISTRICT

The largest number of producing pools in Wyoming are located in the Big Horn basin. This basin is a relatively flat area 75 miles long, north and south, and about 45 miles wide. It is surrounded by high mountains on all sides except the north. The Big Horn Mountains rising 9,000 feet above the level of the plain bound it on the east side; the Owl Creek and Bridger Mountains, which rise to an elevation of about 4,000 feet, bound it on the south side and the Absaroka Mountains, which are 6,000 feet high, form the western boundary. Figure 184, p. 454, gives the location of this basin as well as the position of the surrounding mountains. It will be noted that the center of the basin is filled with Tertiary and Quaternary sediments while the periphery of the basin is occupied by narrow belts of Cretaceous and Paleozoic rocks next to the pre-Cambrian.

In this basin the oil and gas fields are distributed more or less symmetrically around the borders of the basin, as shown in Fig. 184. Among the anticlines known, the following are producing now or have been found productive and are temporarily shut in: Greybull, Lamb, Torchlight, Hidden Dome, Black Mountain, Kirby Creek, Warm Springs, Hamilton Dome, Golden Eagle, Grass Creek, Enos Creek, Buffalo basin, Oregon basin, Byron, Elk basin. The most important of these pools from the standpoint of production is Grass Creek followed by Elk basin, Greybull, Torchlight, Hamilton Dome, Warm Springs and Oregon basin.

Oil was first discovered in Big Horn basin by Edward Lloyd, in 1884, near Bonanza in Paintrock Creek. Four years later, the first test well was drilled nearby but no oil or gas were found, although the well was drilled to a depth of 1,200 feet. Later, small amounts of oil were found, the total not exceeding 50 barrels on the Bonanza anticline. This was enough to encourage further exploration, but not enough to create any great excitement. The next field to be tested was the Torchlight dome, on which the first successful gas well was brought in during 1905. Ten years later, the daily average production of this field was 1,500 barrels per day. Two years before the Torchlight pool was

opened up gas had been discovered on the Byron dome, but no drilling was done until 1906 when a deeper test found the first oil. This pool has to its credit the largest gas well in the state and a fairly good total of oil produced to date. In 1907, the Greybull anticline was found to be oil bearing; in 1912, the Oregon Basin pool was located; in 1914, the first oil well in Grass Creek was brought in; Buffalo basin was discovered the same year, and Elk basin one year later. Practically all of the 50 or more anticlines and domes in the Big Horn basin have now been tested, but not all have been tested to the deepest possible producing horizon.

Tectonics.—The Big Horn basin is a structural as well as a topographic basin. The basement complex upon which the sediments were laid down is very deep in the central portion of the basin, but comes close to the surface in the border zone where the anticlines are located. Beyond these the pre-Cambrian rocks consisting mostly of granite and subordinately of gneiss and metamorphic rocks of other kinds crop out. The difference in elevation of the pre-Cambrian surface on Cloud Peak (13,163 feet above sea level) and the surface under the basin is estimated to be not less than 27,000 feet. The youngest beds which occupy the center of the basin quite completely lie almost horizontal, but have a very gentle dip toward a well-defined middle trough trending N. 40° W. The beds are not entirely undisturbed. Besides several minor folds there is one rather conspicuous one called the "Neiber anticline" in which the Wasatch beds dip very steeply. Toward the outer border the folding becomes more pronounced and around the periphery of the basin several series of highly folded zones of anticlines and synclines are present. These zones are not sharply separated from the upfolds which coincide with the mountains surrounding the basin. The dip of the beds in the border folds amounts to 45 degrees on the average, though dips as low as 10 degrees are common and also some as high as 75 degrees or more are found (Fig. 189). The longest anticline is the Thermopolis which has a crest traceable for 25 miles or more. The others range in size down to 1 mile or less. In some, the axis is foreshortened to such an extent that they are more properly called domes. The Little Grass Creek dome is practically circular and about 1 mile square in area. Some are narrow and have steep limbs, others are wider and have gentle limbs. As a rule, one limb is considerably steeper than the other. Hewett and Lupton state that a line running N. 35° W. separates the

domes and anticlines, which have the basinward limbs flatter, from those in which the basinward limbs are the steeper.

Faults are very common on the anticlines of the border zone. Three sets are recognized by Hewett:[1] The first set occurs as parallel faults transverse to the axis of the anticline. The second radiates outward from the crest of the anticlines, and the third appears at any angle with the axis of the anticlines. The first two sets are probably related to the folding genetically, but the third set appears to be much younger. Most of the faults die out within a short distance of the surface, but are most pro-

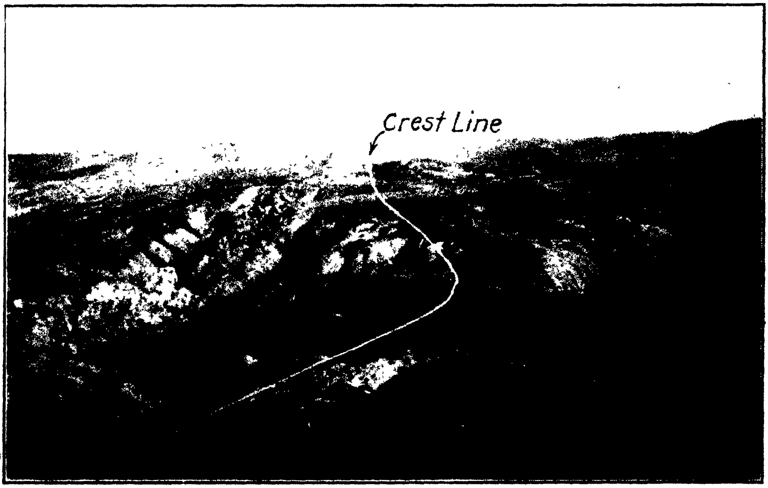

FIG. 189.—Surface appearance of No Wood anticline west of No Wood Creek, between Bonanza and Tensleep. Beds dip in opposite directions from the crest line. (*After U. S. Geol. Survey Bull.* 656, Pl. X.)

nounced in the massive sandstones. In depth they probably offset each other to a certain extent and are absorbed in the interbedded shales. Some have a large displacement at the surface, however, as, for example, one of the Oregon Basin faults which has a throw of 1,250 feet. The great majority have a much smaller displacement.

As to the time of formation of the folds and the faults, the unconformities in the stratigraphic record are used as guides. The youngest Cretaceous formation, the Lance, seems to lie conformably upon the older rocks and has taken part in the deformation of the anticlines. The overlying Ft. Union which

[1] HEWETT. See Bibliography at end of section.

is regarded as Eocene in age is separated from the Lance by a considerable unconformity. At the place where this unconformity is best shown the dip of the Lance is 22° and of the Ft. Union only 9° showing that the Lance had a dip of 13° when the Ft. Union was deformed. In the border zone of anticlines a great thickness of Ft. Union beds is involved in the folding, indicating that some folding took place during the early Eocene. The greatest unconformity occurs between the Ft. Union and the Wasatch. The latter seems to be represented in the border zone only by the uppermost beds of the formation. In other words, *deposition* of *Wasatch* was *going on in the basin while folding was taking place in the border zone.* Even the Wasatch beds have been involved in the folding to some extent. The conclusion thus appears warranted that folding took place earliest in the mountains and then spread progressively toward the basin, making the most basinward folds the youngest in age.

Hewett has also found evidence in the Big Horn basin of a great overthrust which involves a horizontal distance of 28 miles or more, which he calls the "Heart Mountain overthrust." This overthrusting took place later than Wasatch time, and probably in middle Eocene time. McCulloch Peak, near the center of the basin, consists of remnants of this segment of rocks overthrust from the west. After the disturbances had come to an end, erosion of the individual anticlines produced some characteristic features. Because of their height and exposure, the crests of the anticlines suffered more rapid erosion than did rocks in adjacent synclines. In time, a basin was produced which in some cases penetrates great thicknesses of rocks. Often the areal extent of the basin coincides with that of the anticline in a marked manner, as for instance in the Oregon basin.

Stratigraphy.—The section of rocks exposed in the Big Horn basin and in the anticlines around the border includes strata ranging in age from lower Eocene to the Embar formation of Pennsylvanian age. Differential erosion on the anticlines, some of which have a closure of over 2,000 feet, has bared rocks of varying age. The stratigraphic section for the basin was given on page 463. The Embar consists of about 250 feet of sandstone in the western part of the basin, but contains some shale and limestone in the eastern part of the basin. The overlying Chugwater is a characteristically red-bed formation and forms an excellent subsurface horizon marker for that

reason. It contains from 700 to 1,100 feet of red shales and sandstones with a little gypsum in places. The Sundance, above it, consists of grey sandstones and limestones with a thickness of 250 to 530 feet. The Comanchean is made up of two members, the Morrison and the Cloverly. The latter at its type locality consists of two sandstones with a shale zone between them.[1] The upper one of these sandstones is quite important in the Big Horn basin for it is one of the two most productive horizons. It is called the Greybull sandstone and is usually regarded as of the same age as the Dakota. The Cretaceous system is very thick and contains not only the most prolific producing horizons, but also in all probability the most prolific source rocks. The greater part of the 5,600 feet of Cretaceous strata are shales. Some of the shales are distinctly bituminous especially near the bottom of the section and near the middle of the same. About 1,000 feet from the base there is a thick sandstone zone called the "Frontier formation." On the west side of the basin this consists of as many as seven sandstone layers separated by shale zones and on the east side from two to six sandstones are recognized. These layers are usually very lenticular and cannot be traced from pool to pool, but the formation as a whole may be traced. Most of the oil on the west side of the basin has been obtained from the lower sandstones in the Frontier formation. The only other sandstone of any value in the Cretaceous is one called the "Muddy sand" by the drillers. It occurs in the Thermopolis shales about 275 feet above the base (uppermost sand in Lee's Dakota formation). In the Grass Creek field it yields considerable gas, but contains only water elsewhere. The Mesaverde formation stands out somewhat from the rest because it contains coal beds, is dominantly sandy, and more indurated than the other formations above and below.

The Meteetse formation consists of sandstone to the extent of 75 per cent, shale 20 per cent, bentonite 3 per cent, and coal 2 per cent. It varies greatly in thickness from place to place in the basin. The Lance formation contrasts with the Meteetse because it contains practically no coal. It also consists of about 80 per cent sandstone and the remainder shale or clay. The overlying formation, the Fort Union, is separated from the Lance by a great unconformity. In its makeup it is very similar con-

[1] Lowest and middle sandstone of Lee's Dakota group.

sisting of about 75 per cent sandstone and conglomerate and 25 per cent shale. It reaches an enormous thickness in some parts of the basin. The Wasatch formation contains much coarse sandstone and conglomerate as might be expected. A conspicuous feature is the presence of red and green clays alternating with red and greenish sandstones. In the center of the basin the Wasatch is 1,300 feet thick but on the borders it becomes much thinner due to overlap. Probably only the youngest Wasatch is present on the borders where the oil fields lie. The younger rocks consist of volcanic tuff, hot-spring, and alluvial-terrace deposits. Most of this material is probably of Quaternary age.

Producing Horizons.—The producing horizons which have furnished oil and gas in this basin are listed in the table, page 466. The most important horizon is the Frontier formation consisting of sandstones and shales. The sandstones which produce the oil vary in thickness from 5 to 40 feet and in some cases reach a thickness of 130 feet. Together, they make up from one-third to one-half of the formation. Often the upper sands contain water and lower sands oil. The *Peay sand* is one of the sandstones in the Frontier formation. At Enos Creek, the lowest sandstone produces oil and has been called the "Third Wall Creek sand" by drillers familiar with the section in the Powder River basin. Five of the productive pools in the basin produce oil and gas from more than one sand in the Frontier formation. They are Grass Creek, Buffalo, Elk Basin, Kirby Creek, and Golden Eagle pools. Besides these, the Enos Creek, Torchlight, and Lamb pools produce from one of the sands in the formation. The sand next in importance is the Greybull. It is the top member of the Cloverly formation and consists of 10 to 20 feet of yellowish-grey sandstone. Darton believes this upper member of the Cloverly is the same as the Dakota sandstone in eastern Wyoming. Production of oil from this horizon seems to be limited to the east side of the basin where the Hidden Dome, Lamb, Elk basin, and Greybull pools secure oil from it.

Next below the Dakota in stratigraphic order lies the *Morrison* horizon. It produces oil in only one pool—the Grass Creek. The *Embar* sandstones produce oil in three pools; Warm Springs, Hamilton dome, and Black Mountain. The lowest producing horizon is the *Tensleep* sandstone which produces heavy oil at Greybull and in Grass Creek. The Cretaceous oil is fairly

light and runs as high as 45° Bé., whereas the older horizons produce a heavier oil which averages about 22 to 26° Bé.

Typical Pools.—Two pools in the Big Horn basin will be described in detail in order to give a picture of the exact mode of occurrence of oil and gas in this part of the state. *Grass Creek* has been the largest producer of oil and will be described first, since it is perhaps the most typical field. It is located in the southwestern part of the basin. Development began in 1914, but, because of difficulties arising out of the public land withdrawal, drilling of new wells was very much retarded. Certain patented tracts were drilled up in 1915 and 1916. In 1918, when litigation had ceased, drilling went forward rapidly and in September, 1919, a total of 332 wells were producing and had outlined the total area of the pool to be about 1,600 acres.

The Grass Creek anticline coincides with a topographic basin almost exactly. Erosion of the crest has carved out a great thickness of rocks exposing the lower part of the Cody shale in the middle and leaving an escarpment of Mesaverde sandstones to form a rugged boundary around the basin. For that reason the productive sands in the Frontier formation lie rather close to the surface near the axis of the fold and are reached at a depth of 380 to 470 feet. The uppermost bed of sandstone seems to be the most persistent, but almost invariably contains water. The lower sandstones of which there are three in most wells but as many as five in some wells carry oil and a little gas. The thickness of this portion of the Frontier which has the oil-bearing sandstones in it is about 200 feet and the individual layers of sandstone average about 15 to 20 feet. All of them are very lenticular and it is doubtful whether any one could be said to persist over the whole field. As one bed pinches out another begins either at the same horizon or just above or below it, making correlation somewhat difficult. Below the Frontier formation the Mowry and Thermopolis formations have a combined thickness of 880 feet. In the lower part of the Thermopolis, another sand occurs which carries some gas. It is called the "Muddy sand" and ranges in thickness from 35 to 60 feet. This sand by contrast with the Frontier sands is very persistent and uniform in position and thickness. Below the Cretaceous system two other formations have produced oil in this field. They are the Morrison and the Tensleep formations of Comanchean and Pennsylvanian age, respectively. Produc-

tion from the two lower horizons has been small and the oil characteristically heavy.

The structure is that of a typical anticline and it will be noted that the production coincides admirably with the outlines of the structure. Four small local highs with separate closures make small domes on the anticline. The structure contours have been drawn on the top of the Frontier and show a relief of at least 700 feet for this anticline, the contour interval being 50 feet. The basinward dip is gentler than the mountainward dip, the former amounting to 11½° E. and the latter to 29° W. Beds on the surface along the west side attain a dip of 40° in some places, indicating a very disturbed condition along the western edge. Another interesting feature, brought out by the map, is that the productive area is not bounded by the same contour line. On the southeast, production extends 500 feet lower than on the northwest end, and on the basinward side it is 200 to 300 feet lower than on the mountainward side. Furthermore, the water found in the Frontier sands is peculiar and not at all like the saline water usually found in oil fields. It has a high content of sodium bicarbonate and in a general way corresponds closely to a modified surface water.

The question of the *character* of *the water* and its distribution opens up an avenue of approach to the difficult question of the origin of the oil or rather the source of it. Hewett, in *Professional Paper* 145, goes into this problem at considerable length. He states that the water in the Frontier sands does not have the nature of edge water but seems to appear in the sands more or less closely associated with the oil and gas. In other words, a well high on structure produces water with the oil after a certain length of time although, in general, the border wells will go to water soonest and most completely. There does not seem to be very active circulation within the sands as indicated by some wells going dry entirely even on the high parts of the structure. The conclusion therefore seems logical that lateral migration has been less prominent than vertical migration. Also the suggestion first offered by Daly and called the "diastrophic theory of oil migration," according to which oil migrates most effectively when folding of the beds is going on, seems to fit Grass Creek most closely. There is considerable evidence in the thickening of shale beds to support the view that oil and gas might be caused to move about most freely when diastrophism

is going on. Up to the end of 1929, this pool produced a total of slightly over 20,000,000 barrels of oil which makes a per-acre production of 12,500 to date. The total ultimate production of the field was estimated by Hewett at about 22,000,000, indicating

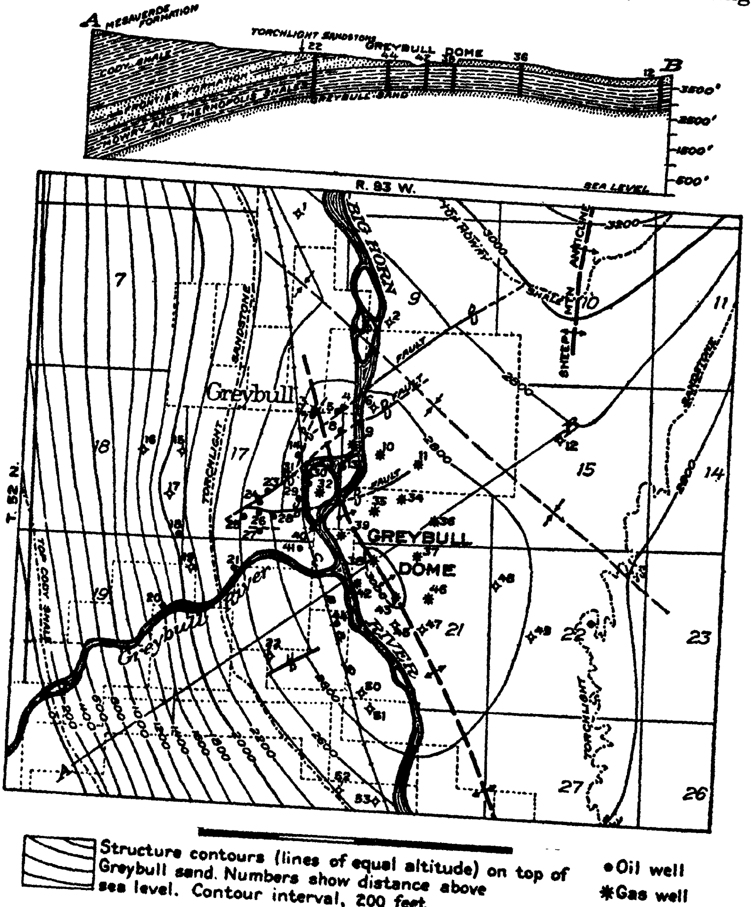

FIG. 190.—Structure-contour map of Greybull dome with a structure section. (*After Hewett and Lupton, U. S. Geol. Survey Bull.* 656, p. 57, Fig. 5.)

that the bulk of the oil has been removed and very little is left in the ground.

The *Greybull* pool is another typical Big Horn basin field. It is located in the northeast part of the basin. The first successful well was drilled in 1907 and, 10 years later, the productive area

had been completely outlined. The shape, extent, and structure of the dome is shown in Fig. 190 by means of contours drawn on the top of the Greybull (Dakota) sandstone. It will be noted that the basinward dip is fairly steep and amounts to 3,000 feet in a distance of about 2 miles, whereas the mountainward dip is scarcely 250 feet in about the same distance. Several faults of slight throw cut the beds in the north half of the dome. Other faults were found in studying the well logs. All of them trend northeast and have their downthrow to the northwest. Erosion of the dome has cut down to the Frontier formation on the top of the dome and even to the Mowry shale in places. The prominent sandstone shown on the surface is the Peay sand which occurs about 75 feet above the base of the Frontier formation. The Mowry has a thickness of 175 feet and contains two sandy layers which are productive in the adjacent dome called the Torchlight dome. They are the Kimball and Och-Louie sands. The dark-colored shales of the Thermopolis formation are 700 feet thick and contain (about 300 feet above the base) the very persistent Muddy sand. Under the Thermopolis formation lies the *Greybull sand*, the *producing horizon*. Its average thickness is 20 feet and it is the topmost part of the Cloverly formation. Some of the early wells in this sand produced as much as 500 barrels daily. The oil has a dark-green color, a specific gravity of about 48° Bé. and has a paraffin base. In this pool oil has been found 1,000 to 1,500 feet lower on the basin-ward side than on the mountainward side. Faults may have played some part in the accumulation of the oil on the west and northwest sides of the dome. Gas is found on the highest part of the dome, and oil on the flank. The maximum production in this field was reached in 1916 when it produced about 4,000 barrels per day. The total production to the end of 1929 amounts to about 750,000 barrels.

Relation of Production to Structure.—From the foregoing descriptions and discussion it will be apparent that the relation between production and structure in the Big Horn basin is remarkably close. Oil and gas have only been found in domes and anticlines with considerable closure up to this time, and as a rule, only the highest parts of the anticline have been productive. Not all the domes and anticlines in the district have been found productive. In fact, the total number out of a possible 50 or thereabouts is quite small. At first it was thought that only the

basinward anticlines would be productive. This has not proved to be the case, however. In recent years, the Enos Creek anticline located some distance west of Grass Creek, has been found productive of gas in the third Wall Creek sand at a depth of 2,800 feet. In the Kirby Creek anticline, which is also one of the mountainward anticlines, oil has been found in the Frontier formation. In the sands lower than the Frontier formation, oil and gas seem to have a wider distribution, although the pools in the deeper sands usually have a more limited areal extent. The fact that the thickness of these lower sands is less and that they involve a greater expense to reach have somewhat dampened the interest at first shown in them.

The original source of the oil and gas in this basin is probably the dark shale in the lower part of the Cretaceous system. During periods of folding it was squeezed out of the shale into the porous sandstones in the section much as a blotter absorbs fluids when in contact with them. This applies particularly to the accumulation in the Frontier sands. The oil and gas in the lower sands may have had a different source. It is quite possible that they derive their oil from a point within the basin and that migration has taken place from the center up the dip toward the periphery, which would allow for a large gathering area to be postulated. On the other hand, the suggestion of Rich that artesian water has flushed the oil and gas along from the outcrop toward the basin also appears to have considerable support. For this theory we must presuppose rather persistent and widespread sandstones so that migration may be effective over long distances. As stated above, the Frontier sands do not appear to be of this type as they are extremely lenticular. The muddy sand, on the other hand, and the Greybull sand are apparently persistent over considerable areas. The distribution of the deeper sands is not well enough known to make any statements about their persistence. In the Muddy and Greybull, water is commonly found instead of oil, perhaps this means that they will be found productive still farther within the basin.

Faults do not appear to have had much influence in trapping the oil although they may have been very effective in guiding its migration. Only two cases are on record where a fault has definitely served to trap any considerable quantity of oil. They are the north dome of the Oregon Basin field and the south dome of the Elk Basin field. The Bonanza anticline illustrates the

ability of a fault to furnish an avenue of migration, for on this dome oil seeps out over a distance of 100 feet along the faulted outcrop of the Mowry formation, but adjacent sands are water bearing. The reason for the lack of fault-trapped accumulations lies in the fact that the massive layers which can support a fault are relatively thin and the shales between the massive layers correspondingly thick.

Production Statistics.—In this district, the largest amount of oil produced from any one dome was from Grass Creek which had a total production of 20,000,000 barrels to the end of 1929. Elk basin which lies partly in Wyoming and partly in Montana produced during the same time about 8,000,000 barrels of oil. Separate figures for the other pools in this district are not at hand. Byron, Greybull, and Torchlight together produced about 1,000,000 barrels to the end of 1927, and Hamilton dome and Warm Springs together produced about the same amount of oil. The other pools mentioned at the beginning of the chapter either produced much less or else they are shut in because of unfavorable marketing conditions in the industry.

WIND RIVER BASIN DISTRICT

The Wind River basin is located in central and west-central Wyoming. It includes portions of western Natrona County and northeastern and central Fremont County (see Fig. 184, p. 454). It is also a structural basin like the Big Horn basin besides being a topographic one. The Big Horn Mountains form a part of the boundary on the northeast; the Owl Creek and Bridger Mountains form the northern boundary; the Wind River Mountains form the western boundary; the Ferris, Seminoe, and Freezeout Mountains form the southern boundary; the Laramie Mountains form the southeastern boundary and the line of folding which connects the Laramie and the Big Horn Mountains through Emigrant Gap anticline and its continuation forms the eastern boundary. It is a fairly flat region in which the soft rocks of the Tertiary-Eocene have formed a blanket over the very much disturbed older rocks. The older rocks project from the covering in a number of places. Rattlesnake Mountain, for example, trending northwest and southeast, lies nearly in the center of the basin and gives us a clue to the tectonic arrangement of the rocks which are concealed by the Eocene strata (see Fig. 186).

The oil fields of the Wind River basin are distributed around the borders and in two sections. One section lies along the eastern border trending northwest parallel to the bounding ranges. This section includes the Bolton Creek, Iron Creek, Poison Spider, Boone Dome, Notches, and Arminto oil pools. Iron Creek, Poison Spider, and South Casper domes lie along the zone of older Cretaceous rock outcrop which extends from Goose Egg Mountain to the South Fork of the Powder River. Bolton Creek lies 15 miles south of Goose Egg Mountain, while Notches and Arminto lie about the same distance northeast and north of Boone dome. The only three which have produced commercial quantities of oil are the Poison Spider dome, and the Notches and South Casper anticlines. The last two together produced about 500,000 barrels of oil up to the end of 1929, while Notches has produced since 1923 about 121,000 barrels of oil.

The second section of producing fields lies on the west side of of the basin, not far from the Wind River Mountains and in parallel alignment with them. Beginning at the north they are the Maverick Springs, Pilot Butte, Hudson, Dallas, Derby, and Big Sand Draw pools. The town of Lander is located close to the Hudson, Dallas, and Derby pools and for that reason these three are often referred to as the Lander field. Figure 184, p. 454, shows that all are located close to the mountains with the exception of the Big Sand Draw anticline. All these pools combined have produced a little over 1,000,000 barrels of crude up to the end of 1928.

Tectonics.—The Wind River basin is apparently not such a simple basin as the Big Horn basin. There is a strong suggestion in the alignment of the border ranges which suggests that it really consists of two basins. The Rattlesnake Mountains may be a continuation of the obscured trend of the Owl Creek-Bridger Mountains and thus divide the basin into subequal halves. Another piece of evidence which points the same way is the occurrence of large oil seepages on the east side of Rattlesnake Mountain. The Dakota sandstone crops out on Wallace Creek and is fairly saturated with a dark asphaltic oil. It is probable that these oil springs supplied the travelers in 1849 who passed through Wyoming by this route. Aughey, the Territorial geologist for Wyoming, described the seepages in 1886 and it was probably on the strength of his statements that the first well in the basin was drilled on Poison Spider Creek near the seepages.

This reached a depth of 1,130 feet and struck oil together with water in a thick sandstone at 500 feet.

Another locality where oil seepages were discovered at an early date is called "Alkali Butte." It lies north of Sand Draw anticline and in the western part of the basin. Here thick oil oozes out of the Frontier sandstones. Oil springs were also known at Dallas as early as 1833, and it was here that the first successful well was drilled in 1907. Development was slow for various reasons, and most of the oil pools in the district were not opened until after 1917.

The anticlines in the Wind River basin are very similar to those described in the Big Horn basin. They are high and have many hundreds of feet closure. The dips on the flanks vary from 20 to 90 degrees. In some of the folds the gentle dips are toward the basin, but in others the opposite relation holds true. Erosion of the crests has removed much rock so that in some of the productive anticlines the Chugwater formation of Triassic age is exposed. This is particularly true of the western side of the basin. The anticlines on the eastern side of the basin have the Cody formation exposed on the crest as a rule. In the case of unproductive anticlines, of which there are many, erosion has cut down to the granite foundation in some cases and in other cases to the Pennsylvanian formations.

Stratigraphy.—The succession of strata in the Wind River basin is given in the correlation table, page 463. There are some differences between the section along the eastern side of the basin and that along the western side, but for ordinary purposes the generalized section will suffice. Hares has given us the best summary for the eastern side of the basin in *Bulletin* 641 of the U. S. Geological Survey. The most recent sections for the west side are given by Collier[1] and Schultz[1] and all the sections coincide very closely except that the more recent ones show a greater number of subdivisions and more accurate details as to thickness and character of rock. For instance, the Cambrian has been subdivided into the Flathead sandstone (250 feet thick) below, the Gros Ventre formation consisting of shales and limestone with a thickness of 600 feet in the middle, and the Gallatin limestone (150 feet thick) at the top. The Big Horn dolomite of Ordovician age is 200 feet thick and consists of massive white and cream-colored dolomite. Above the Ordovician, in the

[1] *U. S. Geol. Survey Bull.* 711, pp. 153 and 702, table opposite p. 36.

western part of the basin, Schultz and Condit have found some strata consisting of shale and thin limestone which they believe are of Silurian and Devonian age. These strata have a thickness of 150 feet.

The more interesting part of the section begins with the Mississippian limestone (the Madison) which has a thickness of from 500 to 650 feet. This formation is usually considered the lowest limit of probable oil production. Oil has been found in it only on Frannie dome in Wyoming, but it has produced considerable amounts in Montana. The Pennsylvanian formations, the Amsden, Tensleep, and Park City, consist of red shales at the base, sandstone in the middle, and shales with thin limestone layers at the top. The Park City formation is a new one, recently set off from the Embar by Blackwelder and Condit. The upper part of the Embar which is of Permian age is called by them the "Dinwoody formation." The Dinwoody formation is given a thickness from 30 to 200 feet and the Park City from 160 to 300 feet. Hard shale, limestone, and chert constitutes most of the formation, but brown shale and phosphate near the middle occurs locally. It is in the sandy layers interbedded with the brown shale that the oil in the western part of the basin seems to occur.

The Chugwater of Triassic age consists of red sandstone and shale with some gypsum, and has a thickness of 1,300 feet. It produces a little oil in the eastern part of the basin and has shows of oil in the western part of the basin. The overlying Sundance is rather more important than the rest because of the production obtained from its sandstones in the eastern part of the basin. It consists of shale, limestone, and interbedded sandstones, the latter carrying the oil. The thickness varies from 200 to 350 feet. The Comanchean rocks called the "Morrison" and the "Cloverly," are clastic rocks laid down in fresh water for the most part and have an average thickness of about 450 feet. They do not contain oil or gas in this basin, although surface seepages from the uppermost layer of the Cloverly (the middle Dakota sandstone) are present.

The Cretaceous rocks from the Mesaverde down to the top of the Dakota were called the "Mancos shale" by Woodruff.[1] Later the subdivisional names of Cody, Frontier, Mowry, and

[1] Lander field, *U. S. Geol. Survey Bull.* 452.

Thermopolis were used and, still later, Schultz and Condit[1] have used the names, Steele, Niobrara, and Carlile for the Cody. The total thickness of the Cretaceous strata is considerable and probably amounts to 5,000 feet in places. Shales make up the bulk of the system and some of them are dark colored and bituminous, especially in the Thermopolis and Cody formations. The sandstones are scattered throughout the system, but are more concentrated about 1,500 feet from the base. This part of the system, called the "Frontier formation" contains from three to five prominent sandstones. The topmost prominent sandstone is usually referred to as the Wall Creek sand, the middle one has no special name as it is not productive in this basin, and the lower one is called the "Peay sand." In the eastern part of the basin, these sands are all medium to fine grained and can be separated by the contained concretions. The Peay is very persistent and contains large brown concretions, the middle one is thinner and less persistent but is characterized by small black chert pebbles. The lowest or Peay sand is productive only in one pool, the Arminto pool in the eastern part of the basin. The upper sand is productive in the Boone dome and the Big Sand Draw, one on the eastern side and the other on the western side of the basin. In the Steele shale which lies just under the Mesaverde there is a rather persistent sandstone called the "Shannon" which produces oil at Pilot Butte and gas in the Boone dome.

The Wind River formation is the name of the Eocene formation corresponding to the Wasatch in the Big Horn basin. It consists of soft shales for the most part, but lenticular sandstones are present and, locally, conglomerates are well developed. These strata are nearly flat lying in this basin and appear in unconformable relations above all older rocks down to the granite. The White River formation, classed as of Oligocene age by Hares, is composed of loosely cemented arkose, sand, and conglomerate. Volcanic material is present in it at some places. Some oil seepages occur to these strata east of Rattlesnake Mountains but the oil is not thought to be indigenous in the formation.

Producing Horizons.—In the Wind River basin the Shannon, Frontier, Sundance, Chugwater, Embar, and Tensleep formations are the producing horizons. The table, page 466, shows these horizons in proper stratigraphic position. The largest amount of

[1] Unpublished notes.

oil in the basin has been obtained from the Embar formation and the Park City member of that formation. The Park City formation in wells drilled in the Maverick Springs pool has a thickness of about 300 feet and contains some thin sands at various intervals in the section. The best oil sands seem to lie near the base of the Park City. It is very likely that the oil in the Lander field, the Hudson, Dallas, and Derby pools, also comes from the same stratigraphic horizon. Next in importance to the Embar horizon is the Sundance formation. In this formation, also, there are thin sandstones separated by shales, a number of which carry oil. The Bolton Creek in the southeastern part of the basin, Iron Creek, Poison Spider, and South Casper pools, all lying north of Bolton Creek, derive their oil mostly from the Sundance sands. At Bolton there is a stray sand in the Chugwater formation which has produced small amounts of oil. The deepest production, stratigraphically, is found at Notches in the Tensleep sandstone. A little oil has also been found in the Tensleep at Maverick Springs.

The Frontier sands have produced very little oil, but considerable gas. At Boone, the Wall Creek sand produces gas at a depth of 2,190 feet and in the Big Sand Draw pool, gas at a depth of 2,550 feet. In the Arminto pool, the gas seems to occur in the third Wall Creek sand (the Peay sand) at a depth of 2,000 feet. The highest oil found in the basin is in the Shannon sand, but very little has been obtained up to date. A number of pools have had shows in this sand and only one—the Pilot Butte—has had any considerable production from this horizon. In the Boone dome gas is found in the Shannon sand.

Relation of Production to Structure.—Very few of the pools in the Wind River basin, which are completely drilled to outline the productive area, have been described. The only one which can be used as an illustration is the Maverick Springs pool described by Collier. The pools of the Lander field were not drilled up when Woodruff described them in 1911. The Maverick Springs anticline is 25 miles long and 9 miles wide. It has a gentle basinward slope and a rather steep mountainward slope as shown by Fig. 191. The anticline trends northwest and southeast parallel to the Wind River Mountains and pitches toward the south. Superposed upon the anticline are three small domes about three miles long and one mile wide called "Circle Ridge," "Big," and "Little" domes. The closure on Little dome amounts

to 4,000 feet, on Big dome to 5,600 feet, and on Circle Ridge dome to 6,800 feet. Accordingly, erosion has cut deepest on Circle Ridge dome where the Embar is exposed. On Big dome the lowest formation exposed is the Chugwater, and on Little dome the oldest formation is the Cloverly. Wells have been drilled on Little dome and Big dome. On the former, a show of gas was found in the only well drilled. On Big dome,

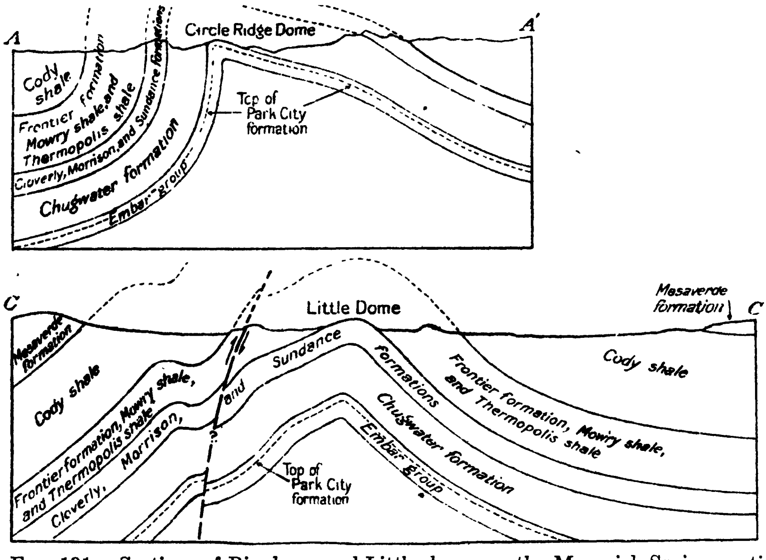

FIG. 191.—Sections of Big dome and Little dome on the Maverick Springs anticline. (*After Collier, U. S. Geol. Survey Bull.* 711.)

quite a number of wells have found oil, but only the top of the dome seems to be productive. It is a heavy asphaltic dark-brown oil with an odor of hydrogen sulphide and has a gravity of about 22° Bé. and occurs in the thin sands of the Park City member of the Embar formation.

Production Statistics.—This basin has not produced very much oil and the quality of it is somewhat inferior to the average Wyoming oil. The combined production of the pools in the western part of the basin up to the end of 1929 has been a little over 1,000,000 barrels. During 1928, the total for the Hudson pool was 187,000 barrels; for Pilot Butte, 20,000 barrels; and for Dallas and Derby pools 58,450 barrels. On the east side of the basin the total production up to the end of 1928 amounts to about

750,000 barrels. Poison Spider and South Casper have contributed the larger part of this. During 1928, Poison Spider produced a total of 349,000 and Notches a total of 9,710 barrels. On account of depressed conditions in the industry some of the pools were shut in most of the year so that the total production figures do not reflect accurately the possibilities of these pools. The gravity of the oil varies with the producing horizon. The Embar oils are heavy with a gravity of from 18 to 22° Bé. and an asphalt base. The oils from the higher sands are mostly paraffin base with a fairly high gravity.

GREEN RIVER BASIN DISTRICT

The Green River Basin district is the largest district in the state. It occupies all of Sweetwater County and parts of Carbon, Fremont, Sublette, Lincoln, and Uinta counties. Like the other basins it is a structural, as well as a topographic, basin. The surface is nearly flat over large stretches and is mostly covered with Tertiary deposits of Eocene age with some Quaternary here and there. It is bounded by major tectonic elements such as the Medicine Bow Mountains on the east, the Freezeout, Seminoe, and Ferris Mountains on the northeast, the Wind River Mountains on the northwest, the Teton Mountains and the rugged zone of folding and overthrusting along the west, and the Uinta Mountain overthrust on the south. The mountains along the east, northeast, and northwest are mostly granitic, with some pre-Cambrian schists occasionally showing along their edges. The western border, however, is somewhat different as is also the southern border. Along the west side, narrow bands of Paleozoic and Mesozoic rocks crop out which are folded into fairly steep anticlines and synclines. Two overthrust faults, the Darby and the Absaroka, have allowed the Paleozoic rocks to come up into juxtaposition with the Mesozoic rocks along nearly north to south lines. The southern border is similarly marked by bands of Paleozoic and Mesozoic rocks, which trend nearly east and west in this case due to the effect of the well-known Uinta overthrust. Figure 192 shows a cross-section of this fault a few miles south of the boundary of the state.

The oil pools which have been developed in this basin may be separated into three groups or sections: The first group lies along the east side of the basin and comprises the Eight-mile

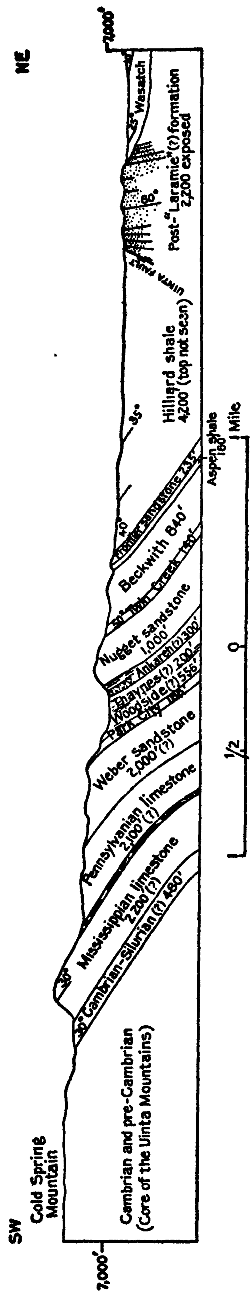

FIG. 192.—Section of beds from upper part of Hilliard shale to Cambrian measured in Vermillion Creek area. (*After Schultz, U. S. Geol. Survey Bull.* 702.)

Lake and Ferris pools, Mahoney, Wertz, and Little Lost Soldier domes, and Crooks Gap and Big Buffalo Basin pools. The second group lies along and nearly paralled to the western border and comprises the Big Piney, Labarge, and Spring Valley pools. The third group contains only one pool, the Baxter Basin gas field, and lies nearly in the center of the basin.

Oil seepages and oil springs were known in this basin since 1844 when trappers and fur traders roamed across the plains. They were first described by some of the Mormons but Veatch[1] gives us the first accurate account of them and describes their location and characteristics. Most of them are located along the Absaroka fault zone, but a few are present in the zone of the Darby fault, on the Labarge ridge. These seepages led to the earliest drilling and to the first successful well in 1907 (on the Labarge anticline). The pools along the east side of the basin were discovered much later, in 1918. In that year, the first commercial oil pool was found on Little Lost Soldier dome in the northeast corner of Sweetwater County. Ferris and Mahoney domes which lie near by were discovered the following year, and the Wertz dome in 1920. The location of these domes is shown in Fig. 184, page 454.

Tectonics.—The tectonics of the basin have been touched upon in the introduction to this part of the chapter. A few details need to be

[1] See *U. S. Geol. Survey Bull.* 285.

added to give a comprehensive picture of the structural setting of the oil fields. The thrust faults which bound the basin on the south and west have been described in detail by a number of geologists. The Uinta thrust fault appears to have allowed old Paleozoic sediments to override much younger strata from south to north for a distance of 4 to 5 miles. The dip of this fault is thought to be about 45 degrees and the displacement amounts to as much as 30,000 feet. The fault comes closest to Wyoming just south of the Baxter Basin field where it lies only about 2 miles south of the border. The two faults along the west, the Darby and the Absaroka faults were described by Veatch and Schultz. In the Darby fault (which is the eastern one of the two) Paleozoic strata as old as Cambrian have been thrust toward the east, as much as 15 miles, over late Cretaceous and Tertiary rocks. The maximum throw is calculated to be about 20,000 feet. This fault, as well as the Absaroka fault, which lies about 20 miles west of the Darby fault, trends nearly north and south and has been traced the whole length of Lincoln County and into Teton County as far as the Snake River Canyon.

It is believed by some geologists who have worked in this region that the Ferris and the Seminoe Mountains are bounded on the west by similar thrust faults. These mountains, together with the Freezeout Mountains, trend northwest and southeast. They seem to lie in an en echelon position with the Wind River Mountains. In both of these mountain groups the ancient granitic rocks have been brought up to the surface and rise high above the plain of the basin. The basin has an average elevation of 6,400 feet above sea level and the highest peak of the Ferris Mountains has an elveation of 10,000 feet.

Stratigraphy.—The stratigraphic section for the two sides and the center of the Green River basin is given in the table on p. 488.

The table of generalized stratigraphic sections is based on the published section of Schultz in U. S. Geological Survey *Bulletins* 543 and 702 for the west side; *Bulletin* 702, and Sears in *Bulletin* 781 for the Baxter basin; Fath and Moulton in *Bulletin* 756, and Dobbin, Hoots, and Dane in *Bulletin* 796 for the east side. It will be noted that the nomenclature for the east side is very similar to the sections we have studied for the Big Horn basin and for the Wind River basin, but the nomenclature for the western part of the Green River basin is quite different.

GENERALIZED STRATIGRAPHIC SECTION FOR GREEN RIVER BASIN

System	Series	East side	Feet	Baxter basin	Feet	West side	Feet
Tertiary	Miocene(?)			Bishop	0 to 200	Bishop conglomerate	
	Eocene			Bridger	0 to 2,000	Bridger	
				Green River	1,500	Green River	2,000
				Wasatch	2,000	Wasatch	3,000
	Laramie			Laramie	1,500	Laramie	
	Montana	Lewis	680	Lewis shale	750	Lewis	
		Mesaverde	2,000	Mesaverde	5,000	Adaville	2,800
		Steele	4,000				
Cretaceous	Colorado	Niobrara, Carlile	1,600	Baxter	3,600	Hilliard	6,000
		Frontier	500	Frontier	100	Frontier	3,000
		Mowry	300	Aspen	400	Aspen	1,800
		Thermopolis	100			Bear River	1,500
	Dakota			Dakota	150		
Comanchean		Cloverly	180			Beckwith	900 to 2,400
		Morrison	400	Morrison	500		
Jurassic		Sundance	300	Twin Creek	125	Twin Creek	2,000
				Nugget	950	Nugget	600
Triassic		Red Beds	1,100	Ankareh	200	Ankareh	500
				Thaynes, Woodside	760	Thaynes	1,500
						Woodside	400
Permian		Park City	160	Park City	115	Park City	1,400
				Weber	1,000	Weber	1,000
Pennsylvanian		Tensleep	360	Pennsylvanian	1,000	Undifferentiated	9,000
		Amsden	210				
Mississippian		Madison	200	Mississippian	1,000		

The Tertiary formations are of little interest to the petroleum geologist for, although seepages are known from them, they do not seem to carry oil in commercial quantities. The Cretaceous rocks are the most important by far, as they have probably furnished the source materials for the oil and gas and also contain the most prolific producing horizons. On the west side of the basin, the Adaville represents the Mesaverde and the Hilliard takes the place of the Steele, Niobrara, and Carlile of the standard section In the Baxter basin the Hilliard is called the "Baxter formation." The Hilliard formation consists of shales with some thin interbedded sandstones. The color of the shale is mostly drab, but some black shale is reported by Schultz. The oil in the Labarge and Big Piney pools probably occurs in the sandstones of this formation. The *Frontier* is

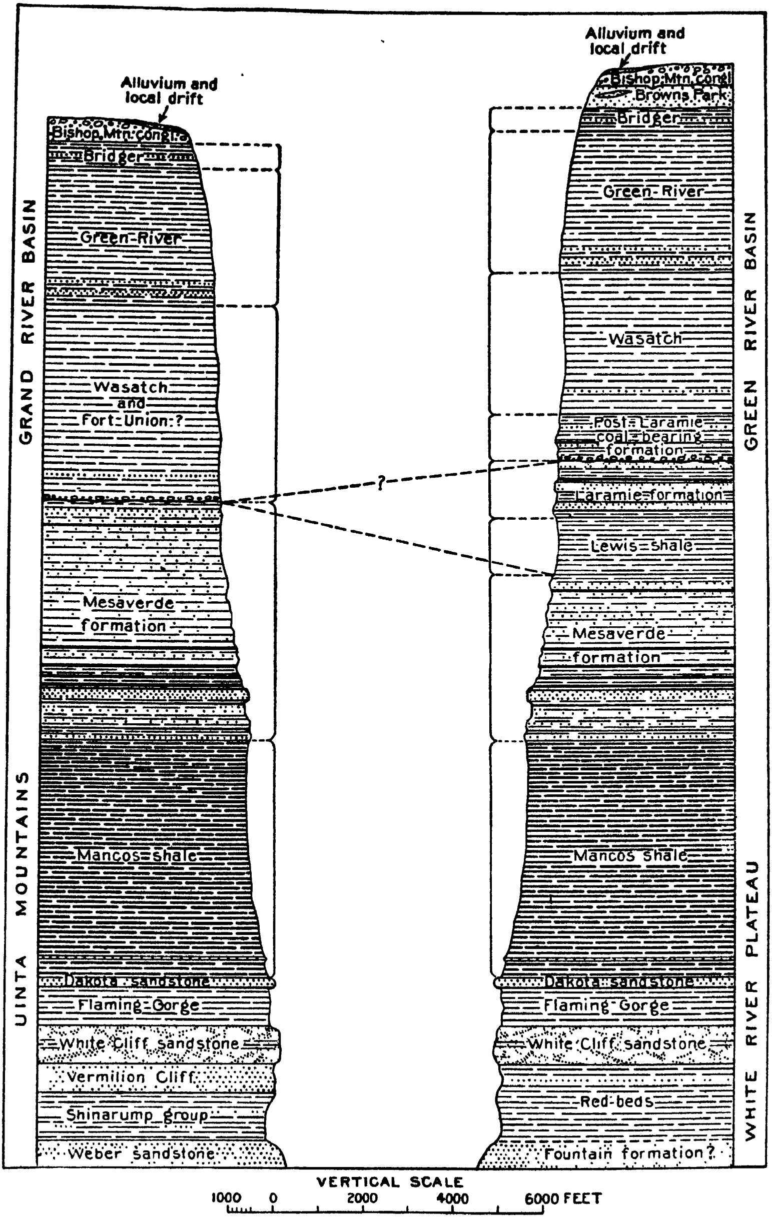

FIG. 193.—Generalized stratigraphic sections for the Uinta basin and the Green River basin. (*After U. S. Geol. Survey Bull.* 415.)

one of the important formations in this basin as it is in the others. It contains oil and gas in the western part of the basin, the gas in commercial quantities, but the oil in small shows only. On the east side it contains much oil as well as gas and is the producing horizon at Lost Soldier and Big Buffalo. As usual, it consists of shale and sandstone interbedded. The underlying *Mowry* and *Thermopolis* formations consist of black shale to a large extent, (as is usual in Wyoming) and the equivalent Aspen shale in the western part of the basin also consists of black or dark-colored shale. These formations, no doubt, furnished the greater part of the oil and gas found in the oil pools of the basin.

The Dakota sandstone has not been separated from the *Cloverly* formation on the east side although the usual tripartite character of the Cloverly would permit it. The Cloverly consists of a hard resistant conglomeratic layer at the base 25 to 75 feet thick, a middle zone of 100 to 150 feet of shale, and a hard quartzitic sandstone 25 to 35 feet thick at the top. The description and sections of the Dakota sandstone in the Baxter basin[1] and of the Vermillion Creek district of Colorado correspond exactly to the description just given for the whole of the Cloverly formation, indicating that these formation names are not being used with precision. Inasmuch as the Dakota sand is the most important producing horizon in the basin this question of correlation of the Dakota and Cloverly takes on added significance. In the Baxter basin the largest gas wells derive their gas from the so-called "Dakota." In the east-side pools oil as well as gas is derived from the Cloverly in the Ferris, Wertz, Mahoney, and Lost Soldier pools. It is the deepest producing horizon that has been found in the basin up to date, with two exceptions; these being important, and opening up new possibilities for deeper drilling. In the Lost Soldier pool, oil was found in the Sundance formation in 1927. The full possibilities of this occurrence are not known at the present time. The other exception is the discovery of gas in the Lakota sandstone on the Wertz dome. In 1930 the Tensleep was found productive on Mahoney dome.

The formations which underlie the Cretaceous in the western part of the basin are the *Beckwith*, *Twin Creek*, and *Nugget* formations. The Beckwith formation as defined by Schultz includes the Dakota (Cloverly (?)) and Morrison of Sears as defined in the Baxter basin. The Twin Creek is the equivalent of the Sun-

[1] SEARS, *U. S. Geol. Survey Bull.* 781-B, p. 19.

dance, and consists of thin-bedded limestone, calcareous shale, and beds of massive limestone. The Nugget sandstone consists of thin-bedded and massive quartzites and sandstones. Indications of oil in the Nugget have been reported by Schultz who states that the white sandstones are often colored dark on the outcrop by bituminous matter and that the rock gives off a strong petroleum odor when freshly broken.[1] The rocks below the Jurassic have oil possibilities, but up to date have not produced any commercial quantities of oil or gas in this basin. The Park City and the Tensleep deserve thorough testing.

Producing Horizons.—In the Green River basin district five producing horizons have been found to contain oil and gas in commercial quantities. Beginning with the youngest they are the sands in the *Hilliard* formation, the sands in the *Frontier* formation, some sands in the *Mowry* formation, the *Dakota* or Cloverly sands, and the *Sundance* formation. The sands in the Hilliard formation produce small quantities of oil in the Big Piney and the Labarge fields on the west side. The Frontier formation, as usual, contains a number of sands throughout a thickness of about 500 feet of strata. The upper sand is called the first *Wall Creek* by the drillers and seems to be the producing horizon at Big Buffalo. The second Wall Creek sand also produces some gas at Buffalo basin as well as at Baxter basin. The third or lowest sand in the Frontier, called the Third Wall Creek sand, produces a little gas at Buffalo basin. At Lost Soldier, erosion in the center of the dome has cut down to within 240 feet of the Frontier formation. Yet oil occurs in the top sand over an area of 160 acres. By way of comparison it may be mentioned that the production from the Mowry shales covers 680 acres and that from the Dakota sand 1,500 acres. Also Lost Soldier is the only field in which considerable amounts of oil have been found in the Frontier sands in this basin, the other fields producing gas only.

The shales in the Mowry formation produce oil in the Ferris, Wertz, and Lost Soldier pools. They are not the major producing horizons in these fields. The Dakota horizon furnishes the most important production in the basin. It has yielded large amounts of gas in the Baxter basin where some wells have a capacity of 50,000,000 or more cubic feet per day. The Dakota formation of the Baxter basin consists of two sandstones separated by a

[1] *U. S. Geol. Survey, Bull.* 702, p. 78.

shale zone about 150 feet thick. Therefore this formation corresponds more closely to the description of the Cloverly than of the Dakota. In the Lost Soldier field, the early wells from the Dakota horizon produced as much as 500 barrels per day and the larger amount of oil produced in the field up to date has come from the Dakota. It is a somewhat difficult matter to explain why this same horizon should produce only gas in the adjacent Wertz dome and *at a lower level.* In the nearby Ferris and Mahoney domes, the Dakota also produces only gas. Ordinarily, gas in the Wyoming fields is of little value except for fuel on the leases. The pools of the east side of the Green River basin are close enough to Casper to have a profitable outlet and it is therefore piped to that city for general use. In 1926, the first well to produce oil from the Sundance was obtained in the Lost Soldier pool. Subsequently gas was found at Mahoney and oil in the Ferris dome.

Relation of Production to Structure.—The structure of the Lost Soldier and the adjacent Wertz domes is shown in Fig. 188, page 461. The former has a closure of 2,500 feet and the Wertz dome of about 1,500 feet. Another map made by Krampert, shows the radial faults about the north and east sides and a closure of about 2,500 feet. A stratigraphic section and geologic cross-section are shown in Fig. 194. These figures show that the axis of the dome trends approximately N. 30° W. and that the dip on the west flank amounts to as much as 45 degrees and on the east flank to 35 degrees. The producing area corresponds very closely to the highest part of the dome and does not extend beyond the area of closure. On the northwest side the wells reach lower down on the flanks than elsewhere but some wells on the north and east are almost as low. Whether this is due to the presence of faults or to some other factor is not known. The best wells were found in the Dakota sandstone in which some wells had an initial production of as much as 4,000 barrels. The two largest wells produced oil which had a temperature of 120°. A sand in the lower part of the Thermopolis formation called the "Muddy sand" also produced some oil. The remainder of the oil comes from the Mowry shales and from the upper Frontier sand.

An interesting fact which was brought out on the Lost Soldier dome during a period of temporary shutdown of the wells is recorded by Krampert. During 1921, the wells producing from

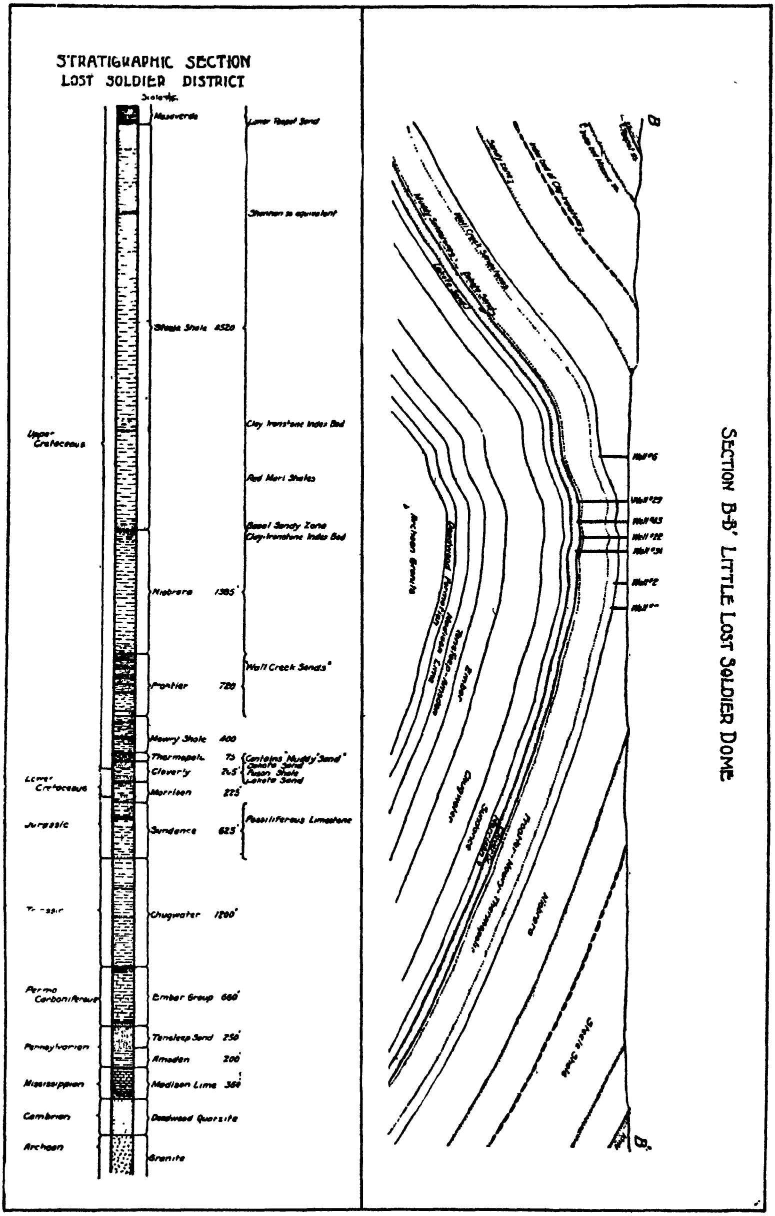

FIG. 194.—Stratigraphic section and geologic cross-section of the Little Lost Soldier dome. (*After Krampert*, *Bull.* A.A.P.G., **7**, 140, Fig. 4.)

the Dakota sand were shut in for a time. A well which had been producing from the Frontier sand and which was producing 80 per cent water with the oil was observed to increase its oil production considerably and to decrease its water production to 10 per cent. The Dakota sand lies 1,200 feet below the Frontier sand, but this quick response to a change in suction on the Dakota sand as reflected in the Frontier seems to indicate a rather close connection between the two horizons. The only explanation for this is that the faults shown on the surface or similar ones cut through both horizons and allow migration from the Dakota to the upper sand. The fact that four horizons are productive on this dome may be due to the same condition. It may also explain why only gas has been found in the Dakota on the adjoining Wertz dome in which this sand lies 2,000 feet deeper, Wertz apparently having no faults.

The oil from the Dakota sand is a paraffin base oil of 32 to 33° gravity, while that from the Frontier is slightly lower, about 31° Bé. In comparison oil from the Ferris dome has a gravity of 39° Bé. and that from the Mahoney dome a gravity of 38° Bé. The porosity of the sand has been tested by the U. S. Geological Survey and found to be 20 per cent for the Frontier sand and 12 to 17 per cent for the Dakota sand.

The Baxter Basin gas field is interesting for a number of reasons. For one thing, it is an exception to the rule that the oil and gas fields occur around the border of a basin, for it lies almost in the center of the Green River basin. Secondly, the structure is perhaps the largest producing structure in Wyoming, having a length of 90 miles and a width of 12 miles. Only a small portion of the structure, however, has been tested so far. The fact that no oil has been found has retarded operations very much. The name of the anticline is Rock Springs anticline. It has gentler dips on its flanks than those of the characteristic Wyoming producing anticlines. The west limb dips from 10 to 20 degrees and the east limb from 5 to 10 degrees. Faults, however, are present in great numbers. They seem to trend obliquely for the most part. The anticline trends nearly north and south, but the faults trend northeast and southwest. Some have been traced a distance of 20 miles. Most of them are normal faults with a small vertical but very large horizontal displacement. The latter amounts to 3 miles in some cases. Three domes, each with a closure of about 300 feet are superposed upon

this anticline. (The anticline as a whole shows 1,750 feet of closure.) All the gas wells drilled up to 1926 are located on these domes. Of a total of 23 wells drilled, 10 are large gassers and the others are either dry or abandoned for some other reason. Both the Frontier and the Dakota sands are productive. The latter has some wells with a production as high as 35,000,000 cubic feet per day to its credit.

An unusually interesting region is the western side of the Green River basin. Here, oil and gas have accumulated under conditions which are quite exceptional. Two thrust faults, the Absaroka and the Darby, appear to be involved in the occurrence of oil in this part of the basin. The Absaroka fault has a great many seepages along its trend and the Darby fault has two oil pools in front of it, the Big Piney and the Labarge pools. Figure 195 shows three cross-sections which indicates that the older Paleozoic rocks have been pushed eastward over the Cretaceous rocks. Tertiary rocks of Wasatch age lie unconformably upon both. In places, the Darby fault shows Mississippian rocks in contact with rocks of the Frontier formation, which means a displacement of 20,000 feet. In front of and under the overthrust lies the Labarge anticline. Oil was discovered on this anticline in 1907 at Big Piney. It is a rather heavy oil with a gravity of about 21.5° Bé. The producing horizon has not been identified with absolute certainty but it is thought to be sands in the Hilliard formation. According to the Wyoming geological survey, the productive area at Big Piney covers about 800 acres and that at Labarge, which was opened up in 1925, covers about 600 acres. The Spring Valley pool in the center of Uinta County has never produced oil in commercial quantities, but oil has been found in a number of wells. Around this pool a great many of the seepages described above are found. The wells were mostly drilled in the region just east of the Absaroka fault, but most of the seepages occur along the more eastern Darby fault line.

Production Statistics.—None of the pools in this basin have produced phenomenal amounts of oil. The best pool is the Lost Soldier dome in northeastern Sweetwater County. It is credited with a little more than 12,000,000 barrels up to the end of 1929. The Ferris field in the same time produced about 100,000 barrels. All the others have produced less than that. During the year 1929, Ferris produced 20,000 barrels, Lost Soldier, 1,284,000 barrels, and Labarge, 765,000 barrels.

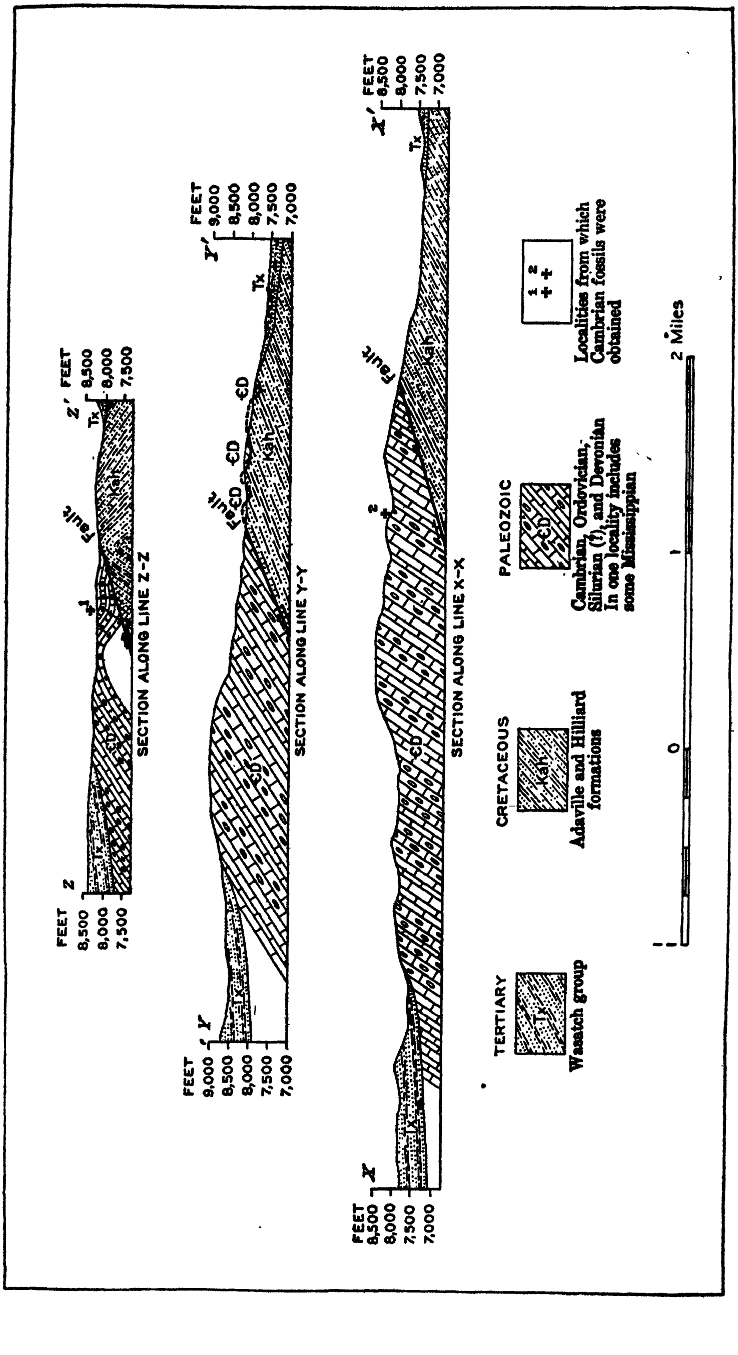

FIG. 195.—Sections across Labarge ridge showing the Darby thrust fault. (*After Schultz, U. S. Geol. Survey Bull.* 543, p. 34, Fig. 2.)

LARAMIE BASIN DISTRICT

The Laramie basin lies in the southeastern part of Wyoming, chiefly in the western part of Albany County and the eastern part of Carbon County (see Fig. 184, p. 454). It is bounded on the east by the Laramie Mountains consisting of granites, gneisses, and schists; on the west, by the Medicine Bow range; on the north, by the Freezeout Mountains. In this basin Comanchean and Cretaceous rocks form the surface for the most part instead of Tertiary rocks as was the case in the other basins. It is a much smaller basin than any of the others and contains only four pools that may be called by that name. These are, beginning in the southeast, the Rex Lake, Rock Creek, Medicine Bow, and Simpson Ridge pools. Of these, Rock Creek is the most important having produced a total of 12,000,000 barrels up to the end of 1929; Rex Lake is next with a total of about 125,000 barrels; Simpson Ridge being third with a production of about 88,000 barrels.

Very little has been published regarding these fields. Our description of them will, therefore, be brief. Rock River was discovered in 1918 and proved to be a valuable find. The main producing horizon is the Dakota sandstone (lowest sandstone of Lee or lower Cloverly) which is encountered in wells at a depth of 2,750 feet. Two other sands also produce some oil. They are the second Muddy (upper Cloverly) and the first Muddy (highest sand of Lee). (See p. 463 for stratigraphic section of the Laramie basin.) These two sands lie 100 and 200 feet, respectively, above the basal Dakota sand. The erosion of the anticline on which the Rock Creek field is located has exposed the Steele formation on the surface. The oil is classed as light oil and present production is close to 3,000 barrels per day. The anticline is asymmetric, 18 miles long, with 2,000-feet closure.

The Rex Lake pool is located on a small sharp anticline in the southwestern part of Albany County. Production is secured from the Dakota and Lakota sands both members of the Cloverly formation. At the surface, the Steele shale of Cretaceous age is exposed and the producing horizons are found at a depth of 3,800 and 3,850 feet. Present production at Rex Lake amounts to about 200 barrels per day.

The Medicine Bow pool is located on a narrow anticline a few miles northwest of the Rock River pool. The Mesaverde

formation is exposed at the surface and the Frontier formation contains the oil at a depth of 4,000 feet. The Simpson Ridge pool was opened in 1925 by the Producers and Refiners Corporation. The first well found production at a rather shallow depth of 655 feet in a sand which is correlated with the Shannon sand. (See table of producing horizons in the Laramie basin, p. 466.) The pool which was subsequently developed is located on the

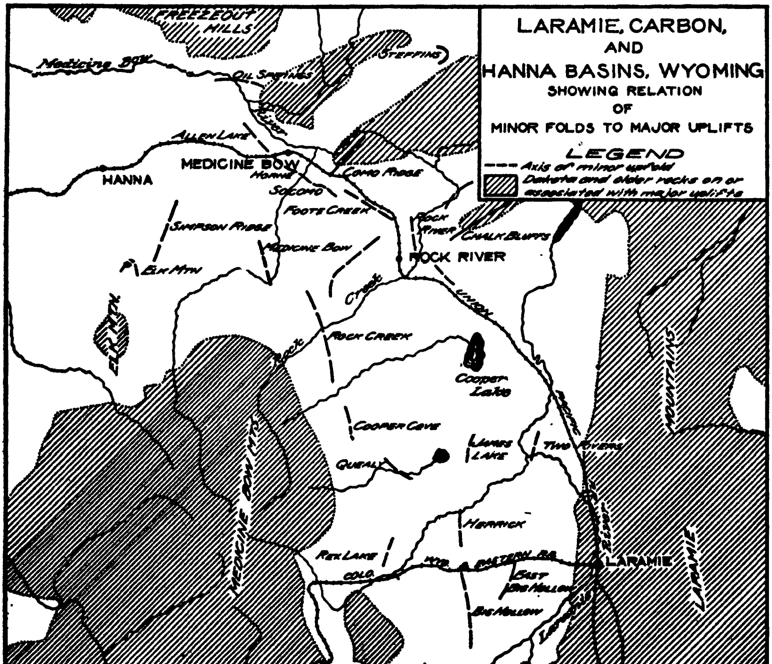

FIG. 196.—Minor and major tectonic elements in Laramie basin. (*After Ball, Bull.* A.A.P.G., **7**, 54.)

crest of an anticline which is narrow and trends northeast. It is located 15 miles southwest of Medicine Bow in Carbon County. On the crest of the anticline the Mesaverde formation crops out so that the Wall Creek sands lie at a depth of about 4,000 and the Dakota at a depth of 5,300 feet. The flanks of the anticline dip steeply, but the closure is small. The present production from this pool is about 100 barrels per day.

POWDER RIVER BASIN DISTRICT

The last of the five districts in Wyoming which we shall consider in this chapter is the Powder River basin. It is located in the northeastern part of the state and includes portions of Sheridan, Johnson, Natrona, Converse, Niobrara, Weston, Campbell, and Crook counties. It is also a structural basin like the rest and is bounded by pronounced positive tectonic elements. On the northwest and west the Big Horn Mountains form the border; on the south the Laramie Mountains bound it; and on the east the Black Hills form the boundary. These three tectonic elements are connected by narrow anticlinal saddle ridges which are mostly concealed by the Tertiary rocks. For instance, between the Laramie Mountains and the Black Hills dome there is clear evidence of a connecting link in the Hartville uplift where granite, schist, and limestone are exposed as at Lusk and

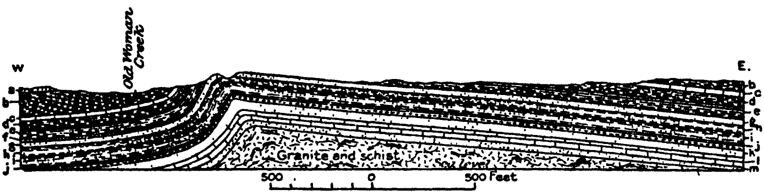

FIG. 197.—Section across the anticline on Old Woman Creek, Converse County, Wyo. (*After U. S. Geol. Survey Bull.* 691.)

at Rawhide Butte. The axis of this connecting link is perhaps indicated by the Old Woman anticline (see Fig. 197) in which the upper Sundance strata are brought up to the surface. The connecting link between the Laramie Mountains and the Big Horn Mountains is indicated by the Emigrant Gap anticline and its continuation—the Cottonwood Creek anticline toward the northeast as shown in Fig. 186, p. 459.

This basin contains the most important oil fields of the state. The largest field is the Salt Creek field which bids fair to become one of the most productive areas in the United States with a probable ultimate total of over 500,000,000 barrels of oil. The second field in rank is the Big Muddy field which has produced about 20,000,000 barrels of oil to date. In third place is the Teapot dome field with a little over 3,000,000 barrels, and fourth, the Lance Creek field with somewhat less than 3,500,000 barrels to its credit. Other pools which have produced a fair

amount of oil are Mule Creek, North Casper Creek, Billy Creek, Osage, and Upton Thornton.

Oil seepages pointed the way to exploration in this part of Wyoming as it did in other parts of the state and the nation. Such seepages were known from early times, especially in the foothills of the Black Hills in the eastern part of the basin. These seepages seem to occur in the sandy members of the bituminous Graneros shale of Cretaceous age, especially in the Newcastle member. Oil booms resulted from the exploration of the seepages at Moorecroft and at Newcastle in 1885 and again in 1900. No successful well was drilled, however, until 1915 in that part of the basin. In that year a good flow of oil was found in the Upton-Thornton district in northern Weston County. Four years later, the first successful well was drilled at Osage in the same county. On the eastern side of the basin success attended the efforts of pioneers somewhat earlier, for P. M. Shannon drilled some shallow wells on the north end of the Salt Creek uplift in 1882. These wells were small and did not arouse the interest they warranted, for it was not until 1908 that the big production under the main part of Salt Creek dome was located. Big Muddy was opened in 1915, Lance Creek in 1917, and Mule Creek in 1919.

Tectonics.—The Powder River basin is a structural basin as shown by contour lines in Fig. 180, p. 449. The surface like the other basins is relatively flat and covered by a thick mantle of Quaternary and Tertiary deposits. Around the borders the older Cretaceous and Paleozoic strata appear in narrow bands, and on the bordering positive tectonic elements, granites, gneisses, and schists of the Archean complex appear. The same forces which produced the large folded areas also produced smaller folds in the basin. Such folds have been found and mapped in considerable numbers, especially around the borders of the basin, where the Cretaceous outcrops make it possible to work out structure more accurately than toward the center of the basin. The Tertiary rocks in the center of the basin lie very nearly in a horizontal position, and therefore do not reflect the anticlines in the more disturbed rocks below. The regional dip around the basin varies, but in a general way the dip is toward the center of the basin at a gentle angle.

Among the anticlines which have been found productive of oil or gas, or both, the Shannon-Salt Creek-Teapot anticline is the

most important. It lies in northeast Natrona County about 35 miles from the eastern border of the basin and parallel to it. This anticline is about 20 miles long and 6 miles wide. The Big Muddy anticline which is located in east-central Converse County is 8 miles long and 3 miles wide. Farther east, the Lance Creek pool is located on an anticline which is at least 18 miles long. These are the largest productive anticlines. A large non-productive anticline, the Powder River anticline located northeast of Salt Creek is 16 miles long and 10 miles wide. Other anticlines have been located and are shown on the map of Wyoming published by the U. S. Geological Survey. Along the eastern side of the basin there are anticlines also, but these have not been found productive up to the time of writing. By contrast, however, some monoclinal structures and terraces have yielded enough oil to entitle them to the rating of oil pools. Such a pool, for instance, is the Osage and the undeveloped areas, Upton-Thornton, Moorecroft, Newcastle, and Wakeman fields.

Stratigraphy.—The succession of rocks in the Powder River basin is similar to the sections described for the other basins. On the western side of the basin the names used for the formations are close to the generalized section for Wyoming, but on the east side of the basin a number of terms are used which are taken from Darton's sections made from the Black Hills region. For the sake of comparison two generalized sections are given on the next page, one for the east side of the basin and the other for the west side. The Cretaceous formations which are the most important from the point of view of the petroleum geologist are represented by four series; the Laramie, Montana, Colorado, and Dakota. The Montana series is subdivided into the Fox Hills and Pierre shale on the eastern side of the basin, and into the Lewis, Mesaverde, and Steele on the western side. The Colorado series is subdivided into the Niobrara, Carlile, Greenhorn, and Graneros formations on the east and the Niobrara, Carlile, Frontier, Mowry, and Thermopolis on the west. The Cloverly formation of Comanchean age is represented on the east side by three formations—the Dakota, Fuson, and Lakota. This is a convenient subdivision because both the Dakota and the Lakota are important producing horizons.

Only a brief description of the formations enumerated in the table above will be necessary at this point, because they are essentially like the formations bearing the same names in the

Generalized Stratigraphic Sections for the Powder River Basin

		West side		East side	
System	Series	Formation	Thickness, feet	Formation	Thickness, feet
Tertiary	Eocene	Wasatch, sandstone, shale, coal	2,400		
		Fort Union sandstone and shale	2,000		
Cretaceous	Laramie	Lance sandstone and shale	3,200	Lance sandstone and shale	
	Montana	Lewis shale and sandstone	1,400	Fox Hills sandstone and shale	50
		Mesaverde shale, sandstone, coal	845	Pierre shale	1,250
		Steele shale and sandstone	2,275		
	Colorado	Niobrara shale	750	Niobrara light shale	200
		Carlile dark shale	225		
		Frontier sandstone and shale	700	Carlile dark shale and sandstone	610
		Mowry dark shale	500	Greenhorn limestone	100
		Thermopolis dark shale	200	Graneros shale and sandstone	900
	Dakota			Dakota sandstone	75
Comanchean		Cloverly sandstone, shale, and conglomerate	150	Fuson shale	30
				Lakota sandstone	200
		Morrison shale and sandstone	250	Morrison sandy shale	150
Jurassic		Sundance shale, limestone, and sandstone	150	Sundance shale and sandstone	350
Triassic		Red beds, shale, sandstone and gypsum	800	Spearfish shale, sandstone and gypsum	500
Permian		Embar	200	Minnekahta limestone	40
				Opeche shale and sandstone, red	75
Pennsylvanian		Tensleep and Amsden	500	Minnelusa sandstone	600
Mississippian		Madison limestone	1,000	Pahasapa limestone	700
Ordovician		Big Horn limestone	300	Whitewood limestone	100
Cambrian		Deadwood sandstone, shale, and limestone	900	Deadwood sandstone, shale and limestone	500

other basins. The Eocene formations—the Wasatch and the Fort Union—consist of a great thickness of yellow sandstone, bluish sandstone, and grey shales with coal lenses. The upper Cretaceous Laramie series consists of massive cross-bedded sandstones with large concretions and a certain amount of shale containing dinosaur and turtle remains. The Montana series consists for the most part of shale, but occasional sandstones are present in the series. One of these sandstones is called the "Shannon sand" after the man who discovered oil in the Salt Creek field. It produces some oil in this basin. The Colorado series is the most important series of rocks in the section for it contains the Wall Creek sands so prolific in the Salt Creek field and productive in other pools also. The Colorado series consists of dark shale to a large extent. About the middle of the

zone lies the Frontier formation which consists chiefly of sandstones (the famous Wall Creek sands underground). Near the base there is another sandy zone which carries oil in various parts of the basin. This sandy zone contains the Newcastle sandstone of the Osage pool for instance and also the productive sands of the Lance Creek field called the "Muddy sands." The black color of much of the shale in this series suggests that it is the source rock of the oil in the basin, at least to a large extent.

The Graneros shale in the eastern part of the basin is subdivided from the top downward into the Belle-Fourche shale 560 feet thick, Mowry shale 150 feet thick, Nefsy shale 50 feet thick, Newcastle sandstone 60 feet thick, and Skull Creek shale 200 feet thick. It is not possible to carry these members across the basin and they are equivalent to the Mowry and Thermopolis on the west side. Lee correlates the Newcastle with the highest sandstone of his Dakota group.[1]

The Cloverly formation, consisting of the Dakota, Fuson, and Lakota, has great importance in this basin. Much oil has been derived from the Lakota member of the formation especially at Salt Creek and at Mule Creek. The Dakota seems to be a non-productive horizon. It either contains water or is dry, except possibly at Lance Creek. The other Comachean formation, the Morrison, consists of green and maroon shales with thin sandy layers at intervals. It seems to have no economic possibilities in the Powder River basin.

The Sundance formation consists of greenish-grey and dark-grey shale for the most part, but some limestone and sandstone are also present in it. The limestones and sandstones appear to be thicker in the western part of the basin. Below the Sundance lies a rather thick section of red beds which are probably equivalent to the Chugwater formation of the western part of the state. In the eastern part of this basin they are called the "Spearfish formation." Still lower formations have no particular interest at present, inasmuch as they either lie too low for profitable exploitation or else have not given any indication of containing oil.

Producing Horizons.—The table of producing horizons, page 466 shows which of the possible productive horizons in the state are actually productive in this basin. The list is probably the

[1] *U. S. Geol. Survey, Prof. Paper* 149, p. 18.

largest which we have had to deal with in the state. The Shannon, First Wall Creek, Second Wall Creek, Third Wall Creek, the Mowry sands, and the Dakota, Lakota, Sundance, and Tensleep horizons are all productive in one pool or another. The horizons which have yielded the most oil up to date are the First and Second Wall Creek sands. Some of the wells in these sands had an initial production of 10,000 barrels when Salt Creek was a young pool. The Lakota sand yielded the largest gusher. One of the wells of the Midwest Refining Company, in the Salt Creek field, came in for 14,000 barrels from this horizon and probably is the largest well ever drilled in the state of Wyoming.

Taking up the producing horizons in stratigraphical order, the facts about each will be summarized briefly. The Shannon sand was the first one to produce oil in this basin. It was found in some shallow wells at the extreme north end of the famous Salt Creek pool in 1882. The wells were small, but long lived. At Big Muddy this sand also furnished a few small wells. The three Wall Creek sands produce oil in the main Salt Creek dome, the Teapot dome just south of it, and in the Big Muddy pool. At Billy Creek oil is also found in these sands but they are not differentiated there. As usual, the Frontier formation in which the Wall Creek sands occur is made up of sandstones alternating with shales. The sandstones are quite variable in extent and thickness as well as in porosity. In some wells a total thickness of sand amounting to nearly 200 feet is logged, but as a rule only certain portions called "pay streaks" produce oil. Such *pay streaks* consist of coarser sand or of finer sand with much pore space due to lack of cementing material. The total zone in which the productive Wall Creek sands appear is nearly 700 feet thick, and while there are three well-defined sandstone zones in this larger zone there are also other sandy zones which are called *stray sands*.

The Dakota sand seems to be productive at only one locality and may be questioned there. This locality is the Lance Creek pool in central Niobrara County, 80 miles east of the Salt Creek pool. Two sands are productive in Lance Creek separated by a small interval of shale. Hancock, who described the pool in 1921, believed the production was coming from the Newcastle sandstone horizon in the Graneros shale. The intervals between sands and their position, however, make it appear probable that they are the Dakota and the Lakota.

The *Lakota* sand promises to be one of the large producers in the basin. At least 30 wells have been drilled to this horizon in the Salt Creek field and the initial production in each case is high with many wells estimated at 3,000 barrels or above. Most of these wells are shut in because of the low prices prevailing for crude oil at the present time. In the Lance Creek pool some of the early wells in this sand had an initial production of 1,200 barrels or more. The thickness of the sand varies at Salt Creek from 50 to 132 feet. Many wells have not penetrated the total thickness and are shut down at a shallow depth in the sand with a large production showing. In the Mule Creek pool the Lakota is found at a depth of 1,370 feet, in the Lance Creek pool at 3,950, and in the Salt Creek pool at 2,500.

The *Morrison* formation has furnished some oil in a few wells at Salt Creek, but its possibilities are not rated very high. The Sundance, however, is destined to produce a large quantity of oil eventually. Only a few wells have been drilled into the Sundance horizon up to the present time although the first producer from the horizon came in during April, 1926. In this first well *three horizons* or sands were found in the Sundance formation. The first sand was dry, but the second at a depth of 2,830 feet produced 1,400 barrels per day, and the third sand over 6,000 barrels per day. Since then several other wells have been drilled to this horizon. The *Embar* sand found at 4,070 feet in Salt Creek produced no oil and the Tensleep found at 4,300 to 4,400 feet was found productive in one well early in 1930. In the North Casper Creek pool which is located in central Natrona County (Fig. 184) the Tensleep horizon has been found to contain commercial quantities of oil. It is found in that pool at a depth of 3,225 feet.

Typical Pools.—The Salt Creek pool is the banner pool of the state and indeed of the Rocky Mountain province. Up to the end of the year, 1929, it had produced 215,000,000 barrels of oil and was running at an average rate of 40,000 barrels per day without using the production from the deeper horizons. This field has been well described by Wegemann and by Beck. It is located on an elongated anticline some 40 miles north of Casper. The anticline is about 9 miles long and 5 miles wide, not counting the Teapot dome, its southern extension. The closure on the dome amounts to about 1,400 feet. The dip on the west side is steepest and averages 1,400 feet in a mile, while the more gentle dip on

the east side amounts to about 1,400 feet in 3 miles. A few faults are shown on Wegemann's map most of them on the east side and most of them normal faults with a small displacement.

On this map the early wells drilled to the Shannon sand are shown at the extreme north end. These wells were located near seepages in the shale and ozokerite deposits along fault planes in the shale. Present production from the Wall Creek sands is located higher on the dome and coincides fairly well with the contour lines, except on the north end where production extends about 150 feet lower on the dip than around the other three sides. The water line lies at about the 3,425-foot contour line measured from sea level. The producing area in the two Wall Creek sands is different and progressively larger downward. For the First Wall Creek sand the productive area covers 5,500 acres and for the Second Wall Creek sand about 22,000 acres. The Third Wall Creek sand is more of a stray sand than are the upper ones, and not very important. The next sand—the Lakota—is estimated to extend over an area of 2,500 acres of which 1,680 are proved. Below the Lakota the Morrison is a possible producing horizon in the future and the Sundance has already been proved to contain large stores of oil. The gravity of the Wall Creek oil is about 36° Bé. and of the Sundance oil slightly lower.

The *Lance Creek* pool is located 85 miles east of the Salt Creek pool in the center of Niobrara County. The first well in the pool was drilled in 1918 and produced 80 barrels. When it was deepened later to the second sand it produced 1,500 barrels. This pool is located on an anticline 18 miles long which lies parallel and close to the Old Woman anticline (see Fig. 197). The trend is nearly east and west. Its north flank is the steepest with dips from 3 to 27° whereas the dip on the south amounts to less than 5°. The closure amounts to about 1,000 feet. The principal production comes from two sands close together at the *Dakota* horizon. Gas has been found in the Lakota and small amounts of oil in the Muddy and Wall Creek sands. The total production of this pool up to the end of 1929 amounts to 3,500,000 barrels.

The *Mule Creek* pool was also described by Hancock[1]. It is located about 100 miles east of the Salt Creek pool and in northeastern Niobrara County. Two anticlines are present here. They trend nearly north and south and the eastern one has a

[1] See Bibliography.

closure of 300 feet while the western and larger one has a closure of 800 feet. At the time the map was made only the eastern one had been found productive and the successful wells are located rather high on the crest of the dome. The first successful well was drilled by the Ohio Oil Company on the eastern dome in 1919. The production since then has a total of about 1,000,000 barrels.

An interesting field, because it differs so greatly in structural conditions from those studied in Wyoming, is the *Osage* pool in northeastern Weston County. Numerous oil seepages at Newcastle and Moorecroft as well as at Osage in the Graneros shale first drew attention to this area, but the first successful well was not brought in until 1919. Two years later there were over 100 wells in the pool producing anywhere from 1 to 50 barrels each per day over a territory covering 36 square miles. Collier, to whom we are indebted for a description of this pool, worked out the structural conditions carefully and found that there is no indication of an anticline such as we are led to expect. Instead, the oil has accumulated on two terraces separated by a zone in which the rocks dip rather steeply. The regional dip in this part of the state is toward the southwest at the rate of about 5 degrees. In the pool area the dip is much less than this on the terraces and is 20 degrees on the separating riser of the upper terrace. On the upper terrace the oil is found at a depth of 100 to 500 feet while oil in the same horizon occurs at a depth of 1,300 to 1,600 on the lower terrace. A subsurface map indicates that the lower terrace may have a slight reversal on it producing a dome of small relief. The oil is found in a sand which lies within the Graneros shale and is called the "Newcastle sand." It lies 200 feet above the base of the Graneros.

As regards the relation of production to structure Collier reports that the best wells are those which lie just west or down the dip from the steeply dipping area between the two terraces. This may be due to the slight reversal of dip in that part of the pool or it may mean a fault at depth. It is interesting to note that good shows of oil were found at many horizons within the Graneros, Greenhorn, and Carlile formations. Examination of these shales under the microscope reveals the presence of much organic matter.

The Osage pool is the only important producing area opened up along the foothills of the Black Hills in the northeastern part of

the Powder River basin. Many wells have been drilled in that territory, however, and quite a number of small ones have been located. The most promising areas of such wells are in the Moorecroft area described by Barnett, the Upton-Thornton area described by Hancock, and the Newcastle and Wakeman areas. In each of these areas practically the same structural conditions were found to exist as in the Osage area. That is, the oil is found in flat-lying beds or on terraces. Inasmuch as there are many areas in that part of the basin which have a terrace structure the expectation that other small pools will be found is not unreasonable. Production from the Osage pool amounts to a little over 1,000,000 barrels.

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NOTE.—See also references for Rocky Mountain Province at end of chapter.

MONTANA

Montana is second in importance as an oil-producing state in the Rocky Mountain petroliferous province. At present there are five pools producing oil in commercial quantities. They are

the Kevin-Sunburst and Pondera pools in north-central Montana (which produced over 3,000,000 barrels in 1929), the Cat Creek pool in central Montana (which produced 500,000 barrels during the same time), and the Lake Basin pool, located 35 miles northwest of Billings, which produced not quite 25,000 barrels in 1929. The Elk Basin pool which was described in connection with the Big Horn basin district of Wyoming lies partly in Montana and the production from the Montana side is sometimes listed separately. In the past, the Devils Basin pool produced a little oil, but not enough to warrant building a pipe line and at present it is shut in entirely. The same applies to the Soap Creek pool.

The first oil well in Montana was located in 1916 in the Elk Basin pool, but inasmuch as this pool lies mostly in the adjoining state, it may be said that the first well on Montana soil was drilled in 1919 when the Devils Basin pool was opened. One year later the first successful well was drilled in the Cat Creek pool, and in 1922 the splendid reserves in the Kevin-Sunburst pool were located. The Lake Basin pool is the youngest and was discovered in 1924. Oil seepages played a small part in this development. Many seepages were reported from different localities, but they usually proved to be iron scum on water or something equally misleading. The only real seepages apparently are the ones found in the Sweetgrass Hills. They helped to make the region about Kevin and Sunburst attractive in the early days of exploration.

Tectonic Elements.—The tectonic elements which have had an influence on the occurrence of oil and gas in Montana are shown in Fig. 180, page 449. If the structure map of this large area is examined, the following features may be located thereon: (1) the Sweetgrass arch with the Kevin-Sunburst dome; (2) the Little Rocky Mountain laccolite district; (3) the Bowdoin dome; (4) the Blood Creek syncline; (5) the Little Belt Mountains; (6) the Big Snowy Mountains; (7) the Bull Mountain syncline; (8) the Lake Basin fault zone; (9) the Crazy Mountain syncline; (10) the Porcupine dome; (11) the large Williston basin in eastern Montana, with the Nesson anticline in North Dakota; and (12) the Cedar Creek or Glendive anticline along the eastern border of the state. These are the tectonic elements which interest us most, for the oil pools and the places where oil shows have been found in dry holes are all located within their confines.

West of this portion of Montana lies the very much disturbed belt of rocks in front of the zone of overthrust faults. The area was described by Stebinger in his report on the oil possibilities of the Blackfeet Indian reservation. The cross-section which accompanies the areal geology map shows that the Lewis overthrust fault is bounded on the east by a zone 25 miles wide in which the Cretaceous and Tertiary rocks are very highly folded and faulted. East of this zone the rocks lie nearly flat or rather rise slowly toward the crest of the Sweetgrass arch which is outlined by the outcrop belt of the Virgelle sandstone.

The Little Rocky Mountains on the north border consist of a large number of small, more or less circular domes which have been produced by laccolithic intrusions. In some of the domes the porphyry of the intrusion crops out at the surface and is surrounded by concentric outcrops of rocks from pre-Cambrian through the Paleozoic and into the Mesozoic systems. The strata are tilted at high angles around the domes, but lie nearly flat away from the domes. The Judith and the Moccasin Mountains are a similar cluster of eroded laccolithic domes. The structural height of the Judith Mountains is no less than 5,000 feet and the topographic height 2,000 feet. The Big Snowy Mountains are due to an asymmetric, elliptical anticline which is 40 miles long and 20 miles wide. The dip on the south limb is steep and ranges from 40 to 60° whereas the dip on the north limb is gentle and amounts to 20° or less.

East of the Judith Mountains and the Big Snowy Mountains lies a very interesting tectonic element. It is a more or less rectangular plateau (structural) with dimensions of 40 by 50 miles and a structural height of 2,000 to 4,000 feet. This has been called the Cat Creek-Devils Basin uplift by Reeves[1] and forms a part of a larger structural unit called by him the "Big Snowy-Judith Mountain anticlinorium." The topographic relief of the Cat Creek-Devils Basin uplift is very slight. To the north lies a syncline called the "Blood Creek syncline" and to the south lies another syncline called the "Bull Mountain syncline." The major trend of this uplift and its chief component members is N. 70° W. It may be thought of as an eastward tilted block of the earth's crust with narrow belts of highly inclined strata at the north and south borders. The north and south borders form elliptical and very unsymmetrical anticlines—

[1] *Bull.* 786 (see Bibliography).

the Cat Creek and the Devils Basin—which give the name to the uplift. Each of these anticlines has a very steep basinward dip amounting to 80° in places and rarely under 60° while the dip toward the center of the central plateau is from 2 to 6° or very gentle. The amount of closure on the basinward side is great, the amount on the plateauward side is much less.

Finally there is a still more subordinate group of structural features which is superposed upon the anticlines. Small, slightly elongated domes a few miles in area, and trending somewhat differently from the main tectonic elements at N. 45° W., lie in a series upon the anticlines. In both the Cat Creek and Devils Basin anticlines these domes have been found productive of oil. On the domes especially, and on the anticlines also there are faults which are parallel to each other and cut the anticline nearly at right angles. This statement applies only to the northern anticline, for on the southern one—the Devils Basin—no faults have been found. Most of them are very short and have a small throw. Another interesting feature which was noticed on the anticlines after drilling had been carried on for some time is the thinning of the shales. On the margin of the uplift the shales are thinned to an extent involving from 20 to 30 per cent of their total thickness. Inasmuch as the Fort Union beds of Eocene age are involved in the folding and the strata below the Fort Union are practically conformable, it appears that the folding and contemporaneous faulting took place in early Tertiary time.

It will be noted from Fig. 180 that there are several other tectonic elements which have about the same trend as the elements described above. The Pole Creek anticline seems to lie nearly on the same trend as the Big Snowy anticline, but is separated by a large fault. The Woman's Pocket anticline lies parallel to the same trend. The Little Elk and Big Elk domes lie in a line which connects up with the Lake Basin fault zone. The former may be laccolithic domes on a fault zone in the basement complex. The latter are interpreted by Thom to be the surface result of horizontal movement along such a deeply buried fault in the basement complex. It will be remembered that Fath first suggested the relationship between deep-seated faults and much smaller faults at the surface trending at a definite angle to the lower fault (see p. 227). The Fig. 198 taken from Thom's excellent article on the structural features of central Montana, indicates the relation between the steeply dipping

asymmetrical anticlines so common in central Montana, and a postulated deep-seated fault along the trend of the axis of the anticline. The Big Coulee-Hailstone dome lies in a similar position north of the Lake Basin fault zone.

The Sweetgrass arch is a very different kind of a structural fold. For one thing it is very large, as the area within the closures amounts to over 700 square miles. Secondly, the dip is comparatively low, for it averages only 60 feet to the mile and rarely exceeds 100 feet per mile. This great arch is open toward the south and pitches at a gentle angle toward the north. The

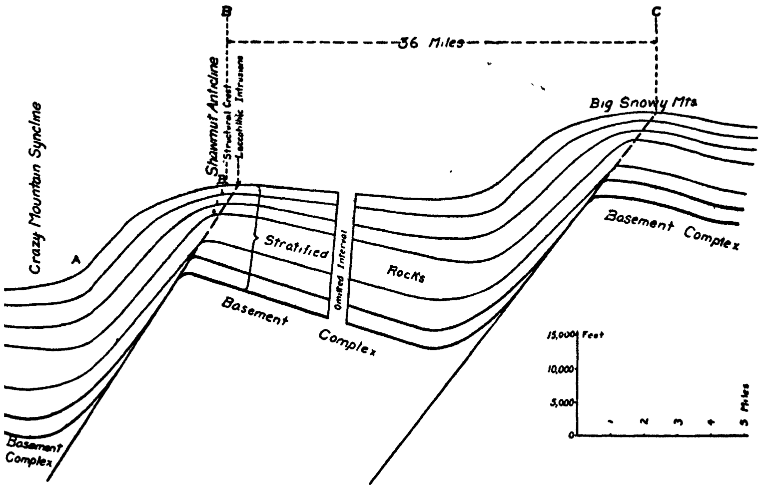

FIG. 198.—Diagram showing assumed relation of surface structural features and subsurface faults in Musselshell valley. (*After Thom, Bull.* A.A.P.G., 7, 12.)

Kevin-Sunburst pool is perched on the northwest side of this great turtleback and thus far only two other commercial pools have been found on it within the United States. In Canada, 60 miles north of the boundary, the Bow Island pool seems to be located on a small dome upon the same arch.

The tectonic elements which have not been emphasized in this discussion such as the Bowdoin and Porcupine domes, Williston basin, etc. are not important at the present time, because no oil or gas has been found in or near them. Nevertheless, that does not imply that they will not become important in the future, because testing of these structural features has hardly proceeded far enough to condemn any of them. The Crazy Mountain

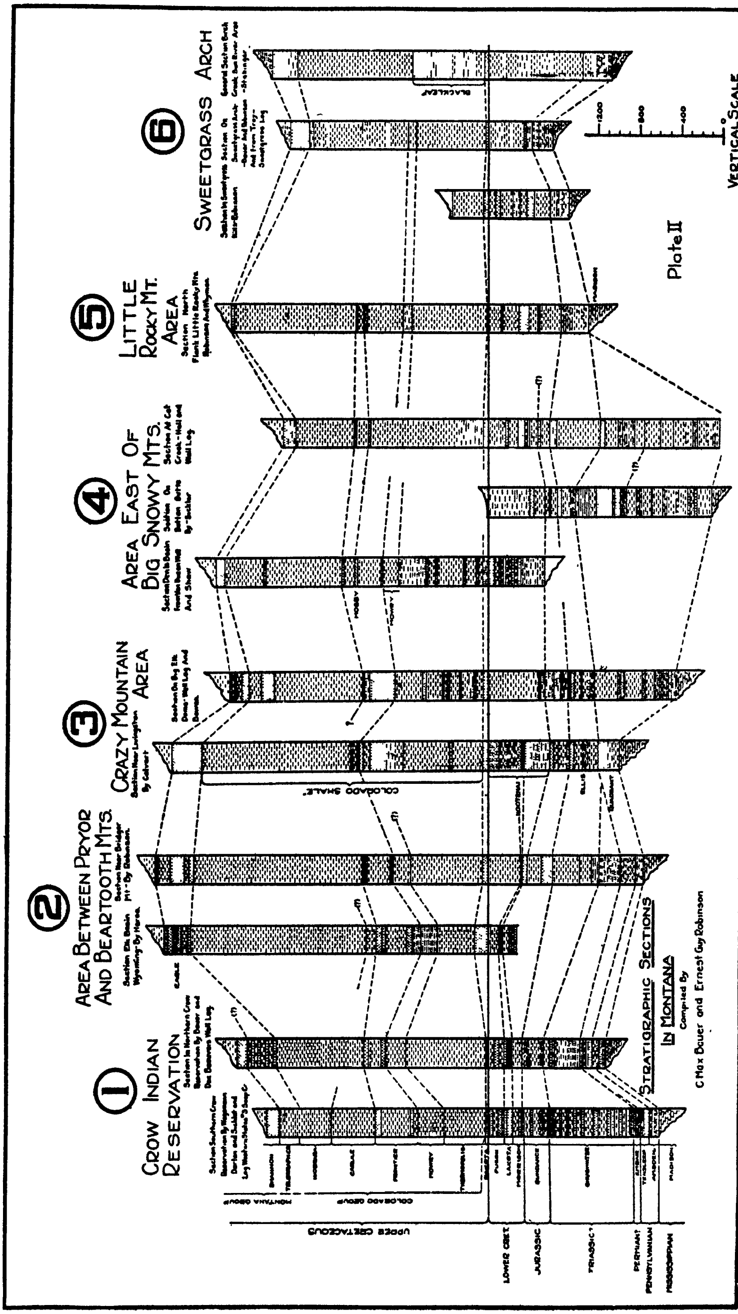

FIG. 199.—Stratigraphic sections in Montana. (*After Bauer and Robinson, Bull. A.A.P.G.,* **7**, 161, Fig. 2.)

syncline seems to be the structural continuation of the Big Horn basin of Wyoming and by some the Big Horn Mountains are thought to be tectonically related to the Lake Basin fault zone and the Big and Little Elk domes.

Stratigraphy.—The rock succession in Montana and its oil fields is very similar to that which we have studied in Wyoming. Some new names are introduced, but a good many are used in both states. Figure 199 shows some comparative stratigraphic sections made in various parts of Montana (according to the location map, Fig. 200) by Bauer and Robinson. Essentially the same formations are listed in the comparative table shown in

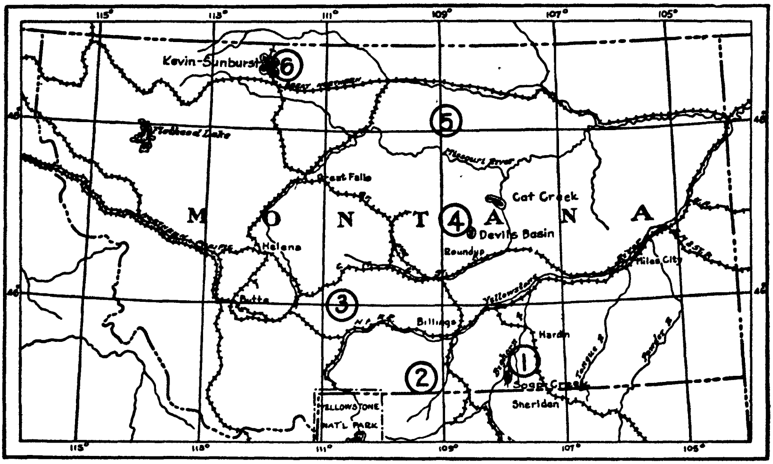

Fig. 200.—Map to show the location of the stratigraphic sections shown in Fig. 199. (*After Bauer and Robinson, Bull.* A.A.P.G., **7**, 160, Fig. 1.)

Fig. 201 which compares the section of northern Wyoming to the sections measured at the localities indicated on the map, Fig. 200. It will be noticed that the Madison limestone is found in all parts of the state, as well as in Wyoming. The Amsden of upper Mississippian age and the Tensleep of Pennsylvanian age are represented by the Quadrant formation in the greater part of Montana. The Embar and Chugwater formations are believed to be missing over the greater portion of the state. The *Sundance* formation of Jurassic age is replaced by the *Ellis* formation and the Cloverly and Morrison of Comanchean age are replaced by the *Kootenai*, and in places the Kootenai and the Morrison. The Colorado series cannot be divided so conveniently in Montana as in Wyoming and is quite commonly left

TABLE OF GEOLOGIC FORMATIONS IN MONTANA.
GIVING THICKNESS AND CORRELATIONS.
By
Bauer and Robinson.

- EXPLANATION -
O • Oil Production
G • Gas Production
• • Show Of Oil
; • Show Of Gas
Figures Indicate Thickness In Feet

PERIOD		NORTHERN WYOMING	LOCALITY #1 SOUTHERN CROW INDIAN RESERVATION	LOCALITY #2 WEST OF PRYOR MOUNTAINS	LOCALITY #3 CRAZY MOUNTAINS	SOUTH SIDE JUDITH BASIN	LOCALITY #4 EAST OF BIG SNOWY MTS.	LOCALITY #5 LITTLE ROCKY MOUNTAINS.	LOCALITY #6 SWEETGRASS ARCH	UPPER SUN RIVER
UPPER CRET.	MONTANA GROUP	Shannon (170)	Shannon (125)	Eagle •(368)	Eagle ; (290)	Eagle (183)	Eagle (115)	Virgelle o (20)	Virgelle (382)	Virgelle ; (380)
		Shale (750)	Sandy Shale (300)	Colorado Shale (2782): Shale (1636)	2688: shale (1440±)	2532: shale (1105)	2255: shale (1185)	2386: shale (1233)	1725: shale (945)	1800: shale (1100)
	COLORADO GROUP	Niobrara (850)	Niobrara (400)	Frontier o cg. at base (287)			Mosby ; (5)	Mosby (?) (6)		
		Carlile (200)	Carlile (400)		cg. (8±)	Big Elk (290)		shale (337)	Mowry (80)	
		Frontier o (300)	Frontier (400)				Mowry (215)	Mowry (80)	shale with thin S.S. ; (700)	Blackleaf (700)
		Mowry • (175)	Mowry (250)	Mowry (167)						
		Thermopolis (350)	Thermopolis (800)	Thermopolis (692)	shale (1240±)	shale (1147)	shale (850)	shale (730)		
		Dakota G (100)	Dakota • (20)	Dakota o (55)	Dakota , (65)	Dakota (50)	Cat Creek o (55)	Dakota (4)	Dakota • (20-30)	Dakota (30)
	HIATUS									
LOWER CRET. (COMANCHEAN)		Lower Cloverly (150)	Fuson (200)	Fuson (313)	Kootenai • (585)	Kootenai • (560)	Kootenai o (535)	Kootenai (701) (not distinguished)	Kootenai G (430-500)	Kootenai (890-920)
			Lakota (100)	Lakota (10)						
		Morrison • (200-500)	Morrison (250)	Morrison (294)	Morrison (185)	Morrison (220)	Morrison (127)			
JURASSIC		Sundance • (200-450)	Sundance • (425)	Sundance (448)	Ellis (277)	Ellis (250)	Ellis (158)	Ellis (254)	Ellis G (180-210)	Ellis (240-310)
	UNCONFORMITY									
TRIASSIC (?)		Chugwater o (800)	Chugwater (600-800)	Chugwater (200-400)	(absent)			(absent)		
	UNCONFORMITY									
PERMIAN (?)		Embar o (350)	Embar (?) (35)	Embar (0-100)						
	UNCONFORMITY									
PENNSYLVANIAN		Tensleep • (150-200)	Tensleep • (50-75)	Tensleep • (150)	Quadrant (200-750)	Quadrant (810)	Quadrant o (1310)			
		UNCONFORMITY								
MISSISSIPPIAN		Amsden (100-350)	Amsden o (150-350)	Amsden (73)						
		UNCONFORMITY						UNCONFORMITY		
		Madison	Madison •	Madison	Madison	Madison	Madison	Madison	Madison	Madison

FIG. 201.—Table of geologic formations in Montana. (*After Bauer and Robinson, Bull.* A.A.P.G., **7**, 162, Fig. 3.)

undivided. It has some sandstone at the base which is regarded by many geologists as the same stratigraphic level as the Dakota of Wyoming. It was so regarded originally by Darton, but subsequent work in many parts of the state has thrown some doubt upon the correlation and the question is still an open one.[1] There is no doubt about the fact that a sandstone at the base of the Cretaceous would be a very convenient marker for stratigraphic correlation purposes, but it is not certain that such a sandstone exists. The sandstones that are now called Dakota in Wyoming may be merely lenses of sandstone in the lower portion of the Colorado, or in the Kootenai.

The *Eagle* sandstone is another horizon about which a certain amount of uncertainty exists. In many places it appears to lie at the base of the Montana series, but in other places it appears to lie higher. There is considerable evidence which indicates that it transgresses stratigraphic zones or levels from north to south and becomes younger in that direction. For practical purposes, however, it is accepted by most workers in the region as the best marker for the base of the Montana series of the Cretaceous system. Its lower member is very widespread and persistent in the northern part of the state and is there called the *Virgelle sandstone.* In the table on p. 519 the author has made two generalized sections for the oil areas of the state including the above formations and some which are not shown in Fig. 201.

The Eocene formations in the table on page 519 need not be discussed further than to say no oil or gas has ever been found in them and that they are non-marine, brackish, and fresh-water sediments consisting of sandstone, shale, clay, and coal. The Cretaceous formations in Montana are the most important for the student of petroleum geology for they contain the most likely source rocks as well as a great proportion of the oil actually produced. The Montana series is usually divided into the Bearpaw, Judith River, Claggett, and Eagle formations. In the Sweetgrass district, the Virgelle sandstone is the approximate equivalent of the Eagle sandstone, and the Two Medicine formation is the approximate equivalent of the Claggett and Judith River formations.

The Bearpaw shale consists of dark-grey and black, bituminous shale of marine origin. It is underlain by the Judith River formation which consists of irregularly bedded sandstone, shale,

[1] Consult Lee in *U. S. Geol. Survey, Prof. Paper* 149, p. 65 and 66.

TABLE OF GEOLOGIC FORMATIONS IN MONTANA OIL DISTRICTS[1]

		Wyoming	Feet	Big Snowy anticlinorium district	Feet	Sweetgrass arch district	Feet
Tertiary	Eocene	Wasatch	1,300			Willow Creek	700
		Fort Union	3,000	Fort Union	1,900	St. Mary River	900
Cretaceous		Lance	1,500	Lance	850		
	Montana	Lewis		Bearpaw shale	1,000	Horsethief sandstone	300
		Mesaverde		Judith River	400	Bearpaw shale	500
		Steele shale		Claggett shale	600	Two Medicine	2,000
		Niobrara		Eagle sandstone	100	Virgelle sandstone	200
	Colorado	Carlile		Warm Creek shale	775	Colorado shale	1,500
		Frontier sandstone	900	Mosby member	50		
		Mowry	250	Mowry shale	400		
		Thermopolis	300	Thermopolis	430		
		Dakota	50	Kootenai	500	Kootenai	350 to 2,000
Comanchean		Lower Cloverly	150				
		Morrison	300	Morrison(?)	200	Morrison(?)	
Jurassic		Sundance	200	Ellis shale, sandstone and limestone	800	Ellis shale, sandstone and limestone	220
Triassic		Chugwater	800	Missing		Missing	
Permian		Embar	350	Missing		Missing	
Pennsylvanian		Tensleep Amsden	150 175	Quadrant		Missing	
Mississippian		Madison limestone	800	Madison limestone	1,500	Madison limestone	770
Devonian		Missing		Jefferson limestone	350	Devonian limestone	335
Silurian		Missing				Silurian anhydrite	275
Ordovician		Big Horn limestone		Big Horn limestone	350	Big Horn(?)	
Cambrian		Deadwood formation		Deadwood	800	Deadwood(?)	1,585
Pre-Cambrian		Schist		Schist		Schist(?)	

[1] Generalized section for Wyoming based on p. 463. Section for Cat Creek Devils Basin district based on *U. S. Geol. Survey Bull.* 786, p. 43 and *Bull.* 736, pp. 172 and 173; section for Sweetgrass arch based on *Bull.* 641 p. 54 and 285 and information from trade journals, etc.

and thin beds of coal deposited in fresh and brackish water. The Claggett shale is very similar to the Bearpaw shale. The Eagle sandstone at the type locality is a marine and brackish-water formation composed of three members. Massive, white

sandstones constitute the upper and lower portions and the middle is made up of shale. In the Sweetgrass district, the upper two members are believed to be missing and therefore the lower sandstone has been named the Virgelle sandstone. On the Cat Creek anticline, the thickness of the Eagle sandstone is 115 feet, but it thins out rapidly toward the east and eventually disappears from the section.

The *Colorado* series is composed largely of dark-colored shales of marine origin. Locally thin sandstones appear in the section and even limestones are known. These are replaced by shale from west to east. In some parts of the state it is possible to make subdivisions corresponding approximately to those established in Wyoming. Such is the case in the Little Rocky Mountains where the Warm Creek shale was named and the Mosby sandstone occurs. This sandstone is recognized in the Cat Creek oil pool and for that reason it is included in the section for that part of the state. It corresponds in position to one of the Frontier sands of Wyoming called the "Wall Creek sands." The Mowry shale may be recognized in the southern part of the state by the splintery or platy grey shale and the fish scales so common in it. The Thermopolis can also be differentiated in southern Montana. On the whole the series is coarser in the south and the west and it is likely that the original land mass which furnished the material for the series lay in that direction.

The base of the Colorado is conveniently placed at the horizon of the Dakota sandstone (uppermost layer of Lee, see p. 452) which may be traced for considerable distances. It is variable in thickness running from 10 to 120 feet and averaging about 50 feet. In many places it contains the worm markings and concretions so characteristic of the formation farther south. In the Cat Creek pool it is the most important producing horizon. There it rests on white or red shale.

The *Comanchean* system consists of fresh- and brackish-water sediments of continental origin with a remarkably uniform thickness from 600 to 700 feet. The Kootenai and the Morrison constitute the two formations which are usually distinguished. In many places they cannot be separated and in that case the name Kootenai probably covers both. In the southern part of the state the Fuson shale with its white and maroon mudstones may be recognized overlying a conglomeratic sandstone, the *Lakota*. Farther north, this distinction cannot be made and the

Kootenai formation supersedes both the lower Cloverly and the Morrison. In the typical Kootenai the shales are *predominantly red* in color. Sandstones occur within the shale mass at fairly regular horizons but not enough sections have been made to correlate these individual sandstones. One of the sandstones is the Sunburst sand of the Kevin-Sunburst field. In the Cat Creek pool, also, a sandstone in the Kootenai produces important quantities of oil and is called the "Second sand."

The *Sundance* and the *Ellis* formations contain abundant marine fossils which are of upper Jurassic age. Also, they are very similar lithologically. Therefore, it is generally believed that they are equivalent. Grey and greenish sandstones and green shales make up the bulk of the formation. The deposits of this formation overlap toward the north over successively older formations. In Wyoming, the Sundance lies on Chugwater sediments. In southern Montana, the Chugwater pinches out and the Jurassic comes to rest upon the Quadrant formation. Finally, in northern Montana, and especially in the Kevin-Sunburst field, it lies directly upon the Mississippian limestone, the Madison formation.

The *Chugwater* formation, therefore is found only in southern Montana. It crops out around the north end of the Big Horn Mountains but is not present in the Big Snowy Mountains, or in the Cat Creek-Devils Basin uplift. Soft, fine-grained sandstones which are massive and red make up a large part of the formation, the remainder being red shale. Typical Embar strata are not known in Montana, although it is thought that the *Phosphoria* formation, in western and southwestern Montana, may be equivalent to it.

The *Quadrant* formation was named after Quadrant Mountain in the northwestern corner of the Yellowstone National Park. There it consists of quartzitic sandstones and shales. Hammer and Lloyd made a very careful study of this formation in Montana and found that it consists of diverse sediments. In the Belt and Big Snowy Mountains the formation consists of red shales, sandstones, and limestone. Fossils collected at a number of places indicate beds of upper Mississippian age, about 800 feet above the Madison limestone. Above this level, the beds seem to be Pennsylvanian. Three sandstone members with an aggregate thickness of 105 feet appear quite commonly in the sections and it is thought that these represent the Tensleep of

Wyoming. The Amsden of Wyoming is represented by 200 feet of sandstones, red shales, and limestones lying right above the Madison limestone. Inasmuch as beds of Chester age are found several hundred feet higher, these beds (correlated with the Amsden) must be of Mississippian age also.

The thickness of the Quadrant varies greatly. The greatest thickness is near Winnett in central Montana between the Yellowstone and Missouri rivers where it reaches 1,400 feet. The formation thins rapidly toward the north and is missing in the Sweetgrass arch district. In southern Montana it has thinned to 300 feet. On the outcrop the Quadrant is often petroliferous. The oil in the Devils Basin anticline comes from the Chester horizon of the Quadrant.

The *Madison* is another one of the important formations in Montana, for it contains large quantities of oil in the Sweetgrass district. As a rule, it consists of massive white limestone. In some places thin-bedded limestone appears in the lower portion, as, for instance, in the Little Rocky Mountain region. In one well on the Sweetgrass arch this limestone was passed through and found to have a thickness of 770 feet. The hiatus between this limestone and the Ellis formation in northern Montana permitted erosion for a long period of time. Therefore, the top of the limestone was very much dissolved and converted into a porous and cavernous condition. Oil has accumulated in these pores and caverns and is found very productive in the Kevin-Sunburst pool. Heald reports one well which penetrated 335 feet of Devonian limestone, 275 feet of Silurian anhydrite, and 1,585 feet of older rocks in this pool. No further information is available regarding these old Paleozoic strata except what may be learned on the outcrop miles away from the oil pools.

Producing Horizons.—The table on p. 523 presents a list of the producing horizons in the oil fields of Montana in stratigraphic sequence and with brief notes regarding their distribution.

The highest producing sand is the *Eagle* sandstone which produces gas at Havre in northern Hill County close to the international boundary. A number of wells ranging from 500,000 to 7,000,000 cubic feet have been drilled in this part of the state and the gas is sold for fuel in Havre. The *Mosby* sand which occupies about the same stratigraphic position as one of the Frontier sands in Wyoming, has produced small amounts of gas in the Cat Creek pool. The first important producing

PRODUCING HORIZONS OF MONTANA OIL FIELDS

Formation	Sand	Thickness, feet	Field	Remarks
Eagle sandstone	Eagle		Havre	Gas, small amount
Colorado	Mosby	8	Cat Creek	Gas, small amount
Dakota	**First sand "Gas" sand Dakota	40	Cat Creek Kevin-Sunburst Lake Basin	Oil, gravity 51° Bé. Gas, small amount Oil, light gravity
Kootenai	Second sand *Sunburst	30 to 60	Cat Creek Kevin-Sunburst	Oil, gravity 47° Bé. Oil, gravity 35° Bé., gas also
Ellis	Stray sands		Kevin-Sunburst	Oil, gravity 42° Bé., small
Quadrant	Van Duzen	8	Devils Basin	Oil, gravity, 24° Bé.
Madison	**Campbell pay Madison (?)		Kevin-Sunburst Soap Creek	Oil, gravity 30° Bé. Oil, gravity 22° Bé. small

horizon is the *First Cat Creek* sand. It produces most of the oil in the field and the area over which it produces is larger than in the Second sand. Its average thickness is 40 feet. A sand in the same or nearly the same stratigraphic position produces a light gravity oil in the Lake Basin pool which was opened by the Midwest Refining Company (35 miles northwest of Billings, in south-central Montana). At Kevin-Sunburst also, the Dakota sandstone is productive. It yields a very small amount of gas in that field.

In the Kootenai formation there are a number of sands, but not all of them are productive. In Cat Creek the third sand in the formation, called the *Second sand* because it is the second producing horizon, furnished the oil in the discovery well. It has contributed much oil since then to swell the total production of the field, but is not as prolific as the First sand. In the Kevin-Sunburst field a sand corresponding in position to the second Cat Creek sand is called the "Sunburst sand." It has produced much gas and oil, although it is not the best sand in the field. The thickness is very erratic and ranges from 0 to 100 feet in very short distances.

In the *Quadrant* formation there are some very petroliferous horizons on the outcrop, the limy layers have liquid petroleum and the shales may be distilled to furnish petroleum. It seems logical, therefore, to expect considerable production where the structure is favorable. This has not been the case, however, although many tests have been drilled on good structures. The only field of any consequence which yields oil from the Quadrant is the Devils Basin field which lies principally in Musselshell County, but reaches over into Fergus County, in south-central Montana. This field was opened in 1919 and has three wells capable of producing about 25 barrels each. There is no pipe-line outlet for this oil. The sand is apparently very thin and may be quite lenticular and the oil from the sand is characteristically heavy oil, resembling the Embar oil of Wyoming.

The *Ellis* formation of Jurassic age produces some oil in the Kevin-Sunburst field from stray sands. The oil is very high gravity oil for this pool and commands a premium. Only a few wells produce from these sands. Most of the oil in the field comes from the top of the Madison limestone which was made porous by solution when it was exposed to erosion. In one well, production was obtained at a depth of 43 feet within the limestone which seems to indicate that the limestone has caverns in it as well as solution holes near the top. The large production which some wells have when they come in also indicates large openings. Many wells have had an initial production of 5,000 to 6000, barrels.

Typical Fields.—It is hardly appropriate to use the term typical fields in connection with Montana, inasmuch as there are so few fields. The two largest differ greatly from each other and more or less from the lesser fields. The tectonics and stratigraphy of both of the fields have been described in the preceding pages, therefore, only a few remarks will be necessary to indicate how these fields differ from other fields in the United States.

The *Kevin-Sunburst* field is located in Hill County in north-central Montana close to the international border. The towns of Sunburst and Kevin along the railroad have given the name to the field. The first successful well was drilled in 1922 and found production at a depth of about 1,750 feet in the Madison limestone. In the next 5 years, nearly 1,200 wells were drilled of which 677 were producing at the close of 1927, 64 were gas wells,

and the rest were abandoned for one reason or another. The wells are in three groups or pools, separated by about 5 or 6 miles one from another. All wells at present are located on the northwest side of the Sweetgrass arch and occupy but a small proportion of the total area of closure on this dome. The average dip of the rocks on the dome is remarkably low for a producing structure in the Rocky Mountain province, for it rarely exceeds 100 feet to the mile and averages closer to 60 feet per mile. The total area within the 700 feet of closure amounts to about 700 square miles.

Most of the oil comes from the porous top of the Madison limestone, but the Sunburst sand is also an important producer. During 1929, this field produced over 3,000,000 barrels of oil, and up to the end of the year the total from the beginning amounts to 21,000,000 barrels.

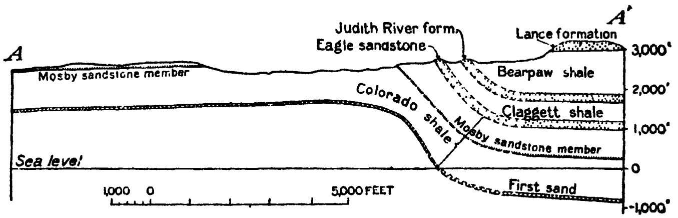

FIG. 202.—Restoration of structure across one of the domes on the Cat Creek anticline (Mosby dome). (*After Lee and Lupton, U. S. Geol. Survey Bull.* 641.)

The *Cat Creek* field has been described by Lupton and Lee as well as by Reeves.[1] This field is located in Garfield and Fergus counties in the Musselshell valley in central Montana. Structurally, it is located on a long narrow anticline which has three domes on it. The domes carry the oil. Figure 202 shows the shape and dimensions of the anticline.

The basinward dip toward the northeast is very steep and the structural height on that side is over 1,500 feet. On the plateauward side the dip is gentle, and the structural height is about 700 feet less. On Reeves map the domes are called the "East," "Mosby," and "West" domes. The central or Mosby dome and the West dome have about the same structural relief, but the East dome is about 100 feet lower, the relief varying from 400 to 525 feet. Faults have cut the domes transversely into many smaller fragments, but apparently have had no influence on

[1] See Bibliography at end of section.

production. They seldom are longer than ½ mile and rarely exceed 100 feet in throw. No doubt they are replaced by other faults in depth either on the same dip trend or with some offsetting. The thick shales absorb the surface faults. Most of the oil seems to have accumulated in the Mosby and West domes and no commercial production is found below the closing contours on these domes. The early wells had an initial production of from 25 to 2,500 barrels. The producing area is largest in the First sand and also best from that sand. The Second sand lies about 150 feet below the First and, if the First sand be considered the uppermost member of Lee's Dakota, then the Second sand might be correlated with the Lakota of Wyoming. A third sand still lower has produced only water. This water, however, as well as the water associated with the oil in the other two sands, is one of the most interesting features of this field. It has a salinity of from 350 to 2,500 parts per million which is not very different from the surface waters or fresh waters of that part of the state. Compare this to the average salinity of the other oil fields of the country which is close to 100,000 parts per million. Apparently, we have here a clear-cut illustration of the influence of artesian water circulation, for the water, no doubt, enters the outcropping portion of the sands in the Big Snowy Mountains, 40 miles west. The much higher elevation there would develop a good head of pressure and it can be seen that the oil, which had collected in the sandstones prior or simultaneously with deformation, might be pushed ahead of the water until it became lodged in some favorable trap. Since the pressure behind the oil is hydrostatic, a great change was noticed in production as the field developed. Much water was allowed to escape in the early days and the pressure lowered rapidly. At present most of the wells in the field are producing some water with the oil. For 1929, the production amounted to 500,000 barrels and the total production from the beginning amounts to about 12,000,000 barrels.

Relation of Production to Structure.—In Montana, no oil or gas in large quantities have been found except on anticlines or domes. Even in this case no worth-while production occurs except in the high portions of the domes. This seems to indicate that the amount of oil which was squeezed out of the Colorado shales into the associated sandstones and similar reservoir rocks was distinctly limited in quantity and, furthermore, that migra-

tion was great and very thorough. The evidence points to the conclusion that circulating waters have had a major controlling influence on the migration and accumulation of the oil and that only highly arched or domed structures were capable of retaining the oil which was brought to them.

Montana is a large state and many anticlines and domes are known to be present which have been inadequately tested. Nevertheless, some testing has been done on practically every known favorable structure and usually with decidedly negative results. The Bowdoin dome should be tested further and perhaps domes like the Porcupine need further testing. Some structures exist under the blanket of Tertiary rocks in the eastern part of the state which deserve favorable consideration.

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See also Bibliography on Rocky Mountain Province at end of chapter.

COLORADO

Colorado has produced considerable oil and quite a little gas since 1887. It can boast of having the second oldest oil field in the United States—the Florence, which was opened in 1862. This field has produced nearly 5,000,000 barrèls of oil since 1905 and a good deal previously, of which there is no accurate record available. One well in this pool produced 622,000 barrels of oil during 30 years of its life. Another remarkable feature about the field is that all the oil comes from shales, no sand horizons having been found up to date.

Seepages of oil, and seepages of gas are common in many parts of the state. Oil-saturated sandstones have been reported from a number of points, and oil shales rich in bitumens are very abundant in the western part of the state. Structural conditions such as produce oil in other parts of the Rocky Mountain province are presènt in great abundance; yet, despite these facts, the number of pools found and the total production of oil has been disappointing. In recent years, a great many wells intelligently located by the best petroleum geologists in the country have proved that many of the best-looking structures are probably dry or contain water in the expected petroliferous horizons. Still when it is considered that the area of the state is very great and that the actual occurrence of oil and gas even in favorable territory is often erratic, we must conclude that the possibilities of the state as a whole are very great.

Up to date, oil and gas in commercial quantities have been found in three different districts or tectonic units. In this discussion these districts will be called (1) the *Julesburg Basin;* (2) the *Green River Basin;* and (3) the *Uinta Basin.* A fourth district in which the possibilities are good for future production

will be described as (4) the *San Juan Basin* district. The first district takes in almost exactly the eastern half of the state from range 41 to range 70, inclusive, or from the meridian of 102° longitude to 105° 30″. The second district lies in the northwest corner of the state and almost wholly in one county, Moffat County. It connects with the Green River basin in Wyoming and belongs to the same tectonic district. The third district lies south of the second in western Colorado chiefly in southwestern Moffat, Rio Blanco, Garfield, and Mesa counties. The fourth district lies in southwestern Colorado in Montezuma, La Plata, and Dolores counties. It connects with the tectonic district in northwestern New Mexico called the "San Juan basin" (see pages 449 and 454).

Tectonics.—The eastern edge of the great Front Range of the Rocky Mountains divides the state into two almost equal halves. The eastern half is very flat in general and covered largely with Cretaceous and younger rocks. The western half is quite the opposite. It is mountainous in the eastern part where the summits of the Rocky Mountains reach elevations above 14,000 feet, and very rugged in the western part where the relief is not quite so great. A zone through the state trending almost north and south between the meridians of 105° 15″ to 107°, or between the ranges of 71 and 86 W., is occupied by the Rocky Mountains. In this zone pre-Cambrian rocks consisting of granite, gneiss, and other metamorphic rocks predominate, although small basins are present in which Paleozoic and Cretaceous rocks appear. West of the longitude 107° there are large basins in which Mesozoic and Tertiary rocks appear. These basins are partly structural and partly topographic. Sometimes the two coincide, but more often they do not. The Uinta Mountains which trend nearly east and west through the northwestern part of the state separate two of the largest structural basins from each other. On the north side of the Uinta axis lies the Green River basin (sometimes called the Washakie basin in Colorado), and south of the axis lies the Uinta basin in both Colorado and in eastern Utah. The Colorado portion of this basin is tectonically separate and is often called the Grand River basin. The positive tectonic element called collectively the "Uncompahgre plateau" separates the Uinta basin from the San Juan basin in the southwestern part of the state. Each of these basins with their contained oil fields will be described separately.

Stratigraphy.—In order to bring before the reader the nomenclature used in the parts of the state in which we are interested, the table on p. 531 has been prepared.

It will be seen from these comparative sections that much the same formations are involved in Colorado as in Montana and Wyoming. Inasmuch as these formations have been described in considerable detail in previous pages only very general descriptions will be given here, and for further details the reader is referred to pages 463 and 519. Rocks of probable Miocene age appear in the Green River and the San Juan basins. The Browns Park formation rests unconformably upon all older rocks including the Eocene Bridger. It consists chiefly of white sandstone with conglomerate at the base. The Santa Fé formation consists of similar materials. The Eocene formations are somewhat more interesting in Colorado than in the other states of the province, because they contain great thicknesses of bituminous shale and have oil and gas seepages at many places. Clay, shale, limestone, marl, sandstone, and conglomerate make up these beds. The middle formation, the Green River, contains most of the oil shale and probably the largest deposits of such shale is in the Uinta basin. In the Green River basin this formation consists mostly of grey shale with the black shale somewhat subordinate. The Wasatch formation consists chiefly of clay shale banded with various shades of red, purple, orange, grey, green, and buff. In the lower portion there is considerable sandstone and some coal.

As usual in this province, the Cretaceous rocks have the greatest value to the petroleum geologist for they contain not only the best oil-bearing reservoir rocks, but also the most favorable source rocks. The Laramie formation contains thin coal beds within shales and sandstones, the Lewis formation consists of grey marine shales with a few thin sandstones. Shales, sandstones, and coal beds make up the Mesaverde formation as well as the underlying Mancos, but the latter contains a large percentage of black and dark-colored shales. The *Dakota* sandstone as described for the Green River, Uinta, and San Juan basins corresponds closely to the Cloverly of Wyoming, that is, it has a threefold character with sandstone above and below and shale in the middle. Therefore, it does not correspond to the accepted usage at the present time which would make the Cloverly only the lower portion of the true Dakota. The Dakota as described

COMPARATIVE STRATIGRAPHIC SECTIONS FOR COLORADO OIL DISTRICTS

	Series	Julesburg basin	Feet	Green River basin	Feet	Uinta basin	Feet	San Juan basin	Feet
Tertiary	Miocene			Browns Park	1,200			Santa Fé	450
	Eocene	Arikaree White River		Bridger Green River Wasatch	 1,500 5,000	Green River Wasatch Fort Union		Wasatch Animas	2,000 400
Cretaceous	Laramie	Laramie	600	Laramie	2,000	Laramie		Laramie	1,600
	Montana	Fox Hills Pierre shale Niobrara	1,000 4,500 to 10,000 400	Lewis Mesaverde	1,000 3,000	Lewis Mesaverde	1,600 1,500	Lewis Mesaverde	800 1,500
	Colorado	Benton	600	Mancos	5,000	Mancos	5,000	Mancos	2,000
	Dakota	Dakota	350	Dakota	250	Dakota	450	Dakota	125
Comanchean		Purgatoire Morrison	300 250	Morrison	500	Morrison	700	Morrison	200
Jurassic		Sundance	100	Twin Creek Nugget	125 950	Twin Creek Nugget	125 950	Navajo Wingate	1,000
Triassic		Lykins	600	Ankareh Thaynes	200 750	Ankareh Thaynes	200 750	Chinle Shinarump Moenkopi	850 100 600
Permian		Lyons sandstone	200	Park City	100	Park City	100	Manzano	1,300
Pennsylvanian		Ingleside Fountain	300 1,600 to 5,000	Weber Limestone etc	900 525	Weber Limestone etc.	900 525	Magdalena	2,000
Mississippian		Milsap	0–100	Madison(?)	600	Madison(?)	600	Missing	
Ordovician and Cambrian		Sawatch, Manitou	0–250	Shale etc.	200	Shale etc.	200	Missing	
Pre-Cambrian				Sandstone etc.	12,000				

for eastern Colorado corresponds to the enlarged Dakota of Lee[1] which includes besides the Cloverly of former writers also the lowest portion of the Colorado series up to and including the sandstone called the "Muddy" by the drillers. Gale's description of the Dakota in the Uinta basin seems to agree with Lee's interpretation and, therefore, has a greater thickness (450 feet) in the comparative sections. The topmost sandstone of the enlarged Dakota is the most important producing horizon in Colorado (see page 452).

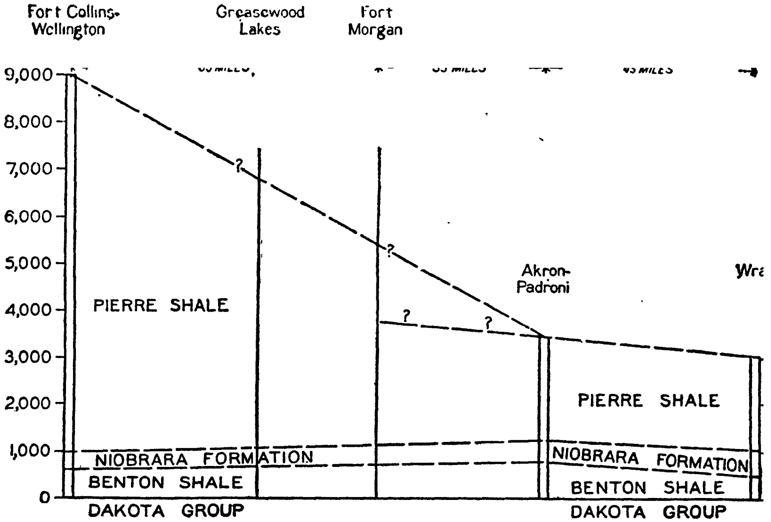

FIG. 203.—Variation, in thickness of Pierre, Niobrara, and Benton formations eastward from the Front range, Colo. (*After U. S. Geol. Survey Bull.* 796.)

The *Colorado* and *Montana series* of the Cretaceous system are subdivided somewhat differently in eastern Colorado. There a thick sandstone called the Fox Hills forms the top of the section. It contains some sandy shale as well as sandstone and varies in thickness from 400 to 2,000 feet. The succeeding Pierre shale has an immense thickness from 4,500 to 10,000 feet and also consists of shales and sandstones. In northeastern Colorado the sandstone members have been named by the geologists who have worked out the detailed structure of that part of the state, because the sandstones are fairly persistent and make good key horizons. The Niobrara formation consists of limestone

[1] *U. S. Geol. Survey Bull.* 751, p. 1–22. See also p. 452 in this book.

and limy shale and has a fairly constant thickness of about 375 feet over great areas. The Benton formation contains dark shale, limestone, and bentonite. A prominent sandstone member of this formation has been named the Niobenton sandstone by workers in that part of the state. Its thickness also is quite uniform over considerable distances. The dark shale in eastern Colorado occupies about the same part of the section as in other parts of the state. It occurs in the lower part of the Benton and within the Dakota, using that term in the enlarged sense as described above.

Pre-Cretaceous Formations.—The formations below the Cretaceous are not very important at the present time in Colorado, inasmuch as little production has been obtained from any of them. Naturally, this does not mean that they will not be found more productive at some time in the future. The Morrison consists as usual of variously colored shales with some marl, sandstone, and limestone. The Jurassic formations called by different names in different parts of the state consist largely of sandstone, although considerable shale and limestone are developed locally. In the northwestern part of the state the sandstones are frequently saturated with oil on the outcrop. Also, small asphaltic deposits are reported along the outcrop of the Nugget sandstone on the south side of the Uinta Mountains. Evidently considerable oil has accumulated in the Jurassic sandstone and it may be looked upon as a possible horizon for future exploration.

Red beds appear in the section below the Jurassic. These are called the *Lykins* formation in eastern Colorado, the *Thaynes-Ankareh* formations in western Colorado, and *Chinle-Shinarump-Moenkopi* formations in southwestern Colorado. Lack of fossils makes it impossible to assign them to a definite position in the stratigraphic column. The *Park City* formation of Permian age consists of limestone, chert, sandstone, and shale. At many places oil indications have been noted in the sandy layers of this formation. The corresponding formations in the San Juan basin are called *Cutler* and *Rico* in Colorado and *Chupadera* and *Abo* in New Mexico.

The Pennsylvanian formations of Colorado include a sandstone which is considered the equivalent of the Tensleep of Wyoming and Montana. This is called the *Lyons* sandstone in eastern Colorado and the *Weber* sandstone in western Colorado. Both

the Lyons[1] and the Weber may be described as a white, to buff, fine-grained, cross-bedded sandstone. No indications of oil have been reported from such a sandstone in this state, but it is still looked upon as a possible oil reservoir because of the production which is obtained from it in Wyoming.

Below the Pennsylvanian sandstone a great thickness of sedimentary rocks of all kinds have been reported from well logs and may be found on the outcrop. They have little importance at present. Perhaps the most interesting portion of this thick succession of strata is the red quartzite named the *Uinta group* by Powell. It has a thickness estimated at 12,000 feet and is seen chiefly in the Uinta Mountains and along the trend of the mountains where local uplift has occurred. Lack of fossils makes it impossible to assign them to a definite position in the time scale, but they are usually regarded as of Algonkian age. Below them and below higher Paleozoic strata in different parts of the state, only granite, schist, and other pre-Cambrian rocks may be looked for.

Producing Horizons.—Six productive horizons have been found in the state of Colorado up to date and of these 3 are sandstones. The Pierre shale produces oil in the Florence and Cañon City pools; the Mesaverde shale produces oil in the Uinta basin (in the De Beque pool) and the Mancos shale produces oil in the Rangely pool in the same basin and the Tow creek pool of Green River basin. The production from the De Beque pool has been very small and the Mesaverde therefore cannot be looked upon as a very important horizon for future exploration. The Mancos shale production should be considered more seriously as it seems to be capable of yielding great quantities when structural conditions are favorable. The Pierre shale must be looked upon as a very good producing horizon and will no doubt produce oil at other places than Florence and probably in worth while quantities.

The *Muddy* sand which is the highest sandstone in the Dakota formation appears to be the only true sand horizon which is producing commercial quantities of oil in Colorado at present. The first production in this horizon was discovered in 1923 in the Fort Collins dome of the eastern district. In the same year, oil was also found in the same sandstone in the Green River

[1] Consult *U. S. Geol. Survey, Prof. Paper* 149, pp. 5 and 26 for correlation of Lyons and Ingleside.

basin near Craig in the Moffat (previously Hamilton) dome. The Muddy sand really lies in the basal portion of the Colorado shale, but according to the recent correlation studies of Lee has been included in the Dakota formation and will probably be so considered in the future. In the eastern district of Colorado where the Dakota can be studied conveniently on the outcrop near the producing area it varies in thickness from 285 to 425 feet. It consists of three sandstone zones separated by two shale zones. The lowest sandstone is usually coarse grained or conglomeratic. It rests unconformably upon the channeled surface of the Morrison formation and ranges in thickness from 25 to 75 feet. The lower shale is a sandy shale of unusual colors, red, purple, and green being common, of a thickness varying from 25 to 65 feet. The middle sandstone is grey, hard, quartzose, and even bedded. It averages 12 feet in thickness but may be as low as 6 feet and as high as 53 feet. The upper shale which used to be classed with the Thermopolis formation of the Colorado series, is a thick section of dark to black bituminous shale. Along the Rocky Mountain front ranges it varies from 110 to 240 feet. The upper sandstone (which the drillers like to call the "Muddy" sand) varies greatly in character and thickness, more so than the other two members. At places it is soft, granular, and porous while at other points it is a hard, firmly cemented, quartzitic sandstone which would be of no value for storing oil or gas. Its thickness ranges from nothing to 80 feet and may be entirely lacking over considerable areas. Carbonaceous streaks are common in it and peculiar *fucoid* markings and *worm* trail marks serve to distinguish it from the lower two sandstones.

By way of summary the producing horizons of Colorado are grouped in the following table on p. 536, page 454.

Julesburg District.—In the eastern part of the state oil and gas in quantity have been found at Florence and in the Fort Collins dome. A small amount of oil has also been taken out of the ground near Boulder. Gas has been found in Yuma County and also on the Walden structure in the northeastern part of the state. These areas as well as the producing pools in other parts of the state are shown in Fig. 184, p. 454.

A cross-section to show the structure of the Florence field is reproduced in Fig. 204. Smaller structures near Florence and Cañon City as well as the Wild Horse anticline are also indicated. The area of the old Florence pool is indicated and appears to

PRODUCING HORIZONS OF COLORADO OIL DISTRICTS

System	Formation	Sand	Thickness, feet	Where productive
Cretaceous	Pierre	Shale	500	Florence field in Eastern district
	Mesaverde	Shale		De Beque pool in Uinta basin
	Mancos	Shale	100	Rangely pool in Uinta basin. Tow Creek and Iles in Green River basin
	Dakota	Muddy		Green River basin, Moffat, and Thornburg. Uinta basin, various gas pools. Eastern district, Fort Collins
Comanche	Morrison	Morrison	30	Moffat, Iles and Thornburg
Jurassic	Nugget	Sundance	60	Green River basin, Moffat, and Iles

cover a good share of two townships. The area of the newer Cañon City pool is about 6 square miles. The importance of the Florence-Cañon City field lies not so much in its production record as in its unique features and these entitle it to considerable space in this volume. In the first place, this is the only field in the United States which has constantly produced large quantities of oil from shale. Discovered in 1862 near an oil spring known to the Indians, it has produced more or less oil every year since then ending up with a production of 294,000 barrels for the year, 1927. The life of the wells is from 1 to 33 years and the maximum produced by any one well is 622,000 barrels. Over 1,000 wells have been drilled and the ratio of producers to dry holes is better than 3 to 1. The depth in wells as to production varies from 1,100 to 3,600 feet, but the best producing zone seems to be 500 feet thick and is all shale without any sign of sandstone. The coal fields are not very far distant (½ to 3 miles) and the carbon ratio of the coals is about 57 per cent. The oil horizon lies 2,200 to 3,400 feet above the coal horizons, or 1,900 to 2,400 feet above the Dakota sandstone. In other words, the oil occurs in the Pierre shale at a distance of about 1,000 to 1,500 feet above the Niobrara shale top.

Tectonically, the Florence field lies in a structural basin called the "Julesburg basin." This basin is large and covers

portions of Wyoming, South Dakota, Nebraska, and Kansas as well as Colorado. It is bounded by the following positive tectonic elements most of which we have become acquainted with in previous chapters: The Black Hills form the northeastern boundary, and the Cambridge anticline, which trends southeast toward Norton in Kansas, bounds it on the east. Along the southeast it is bounded by the *Sierra Grande arch* and *Apishapa anticline.* The west side is bounded by the Laramie and Colorado Front Range of the Rocky Mountains. The deepest part of this basin seems to lie close to the western boundary and quite close to the Rocky Mountain front. It forms a long narrow trough with deeper small depressions in it. The basin as a whole measures about 400 miles in diameter along both major axes. As the crosssection in Fig. 204 indicates, the Florence field lies on the edge of the deep western trough in such a position that we can hardly speak of favorable structure for the trapping of oil. The only way such trapping can be explained in this location is by assuming that the shales are wrinkled and faulted on a small scale, allowing small openings and crevices to form or to exist. Oil from the bituminous shales in the section has accumulated in these minute spaces in sufficient quantities to make an oil field possible. No sandstones are found in the section to speak of until the Dakota is reached and it contains only water. The fact that Cambrian, Ordovician, and Mississippian rocks occur in this particular

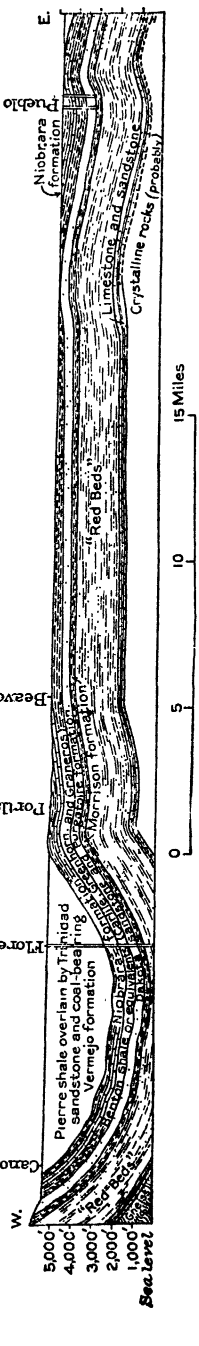

FIG. 204.—Section along Arkansas valley from Pueblo to Cañon City. (*After U. S. Geol. Survey Bull.* 716.)

embayment (often called the "Cañon City embayment") and not along the rest of the trough seems to indicate that this particular area was the site of almost continuous subsidence near shore, which would mean an abundance of source material for oil and gas. A remarkable feature of the field is that water is never encountered, although a small amount of gas is usually present with the oil. There is never enough gas to cause a flowing well and all wells drilled from the beginning have been pumping wells.

The total production from the Florence and the Cañon City (opened in February, 1928) pools, up to the end of 1928, amounts to nearly 5,000,000 barrels which is a remarkable showing for a shale-producing horizon. The gravity of the oil ranges from 20 to 30° Bé. in the Florence pool, and from 30 to 33° Bé. in the Cañon City pool.

Many test wells have been drilled in the Julesburg basin on local anticlines and on large domes or anticlines, but no important production has been found so far except at Fort Collins. Figure 184 shows the most prominent structural elements in northeastern Colorado as well as the Fort Collins and associated domes. The Fort Morgan anticline has not been tested completely and up to date only small gas wells have been found on it. That is considered very encouraging, however. It is separated from the Fort Collins-Wellington anticline by the Greeley syncline.

The first well in the Fort Collins pool was a gas well with terrific pressure. It was unexpected and therefore not brought under control immediately, blowing wild for 50 days. The actual flow of gas was estimated at 80,000,000 cubic feet. It was a wet gas from the first and later the well turned to oil flowing about 400 barrels from a depth of 4,283 feet. The Fort Collins dome is one of numerous domes perched on an elongated anticline which parallels the Front Range. It has a closure of 350 feet, a length of 3 miles and a width of 1 mile. The Wellington dome lies 9 miles north of the Fort Collins dome measured from the highest point on each. It has a much larger closure as well as greater length and width. The closure on the Wellington dome amounts to over 1,300 feet; the length is 8 miles and the width 1½ miles. The anticline on which the two domes are located is at least 14 miles long, has a west dip of 10 to 15°, and a dip on the east flank of 5 to 10°.

The producing horizon in these two domes is the uppermost sand of the Dakota formation usually called the "Muddy" sand. It is apparently 30 to 40 feet thick and very porous. In the few wells drilled on the Wellington and Fort Collins domes the production per well has been large and the gas pressure high. The total production for 1929 was nearly 1,000,000 barrels and the total from the beginning was 5,000,000 barrels.

Between the Florence field and the Wellington-Fort Collins pools very little oil has been found although seepages are fairly numerous. One of the most interesting seepages is reported

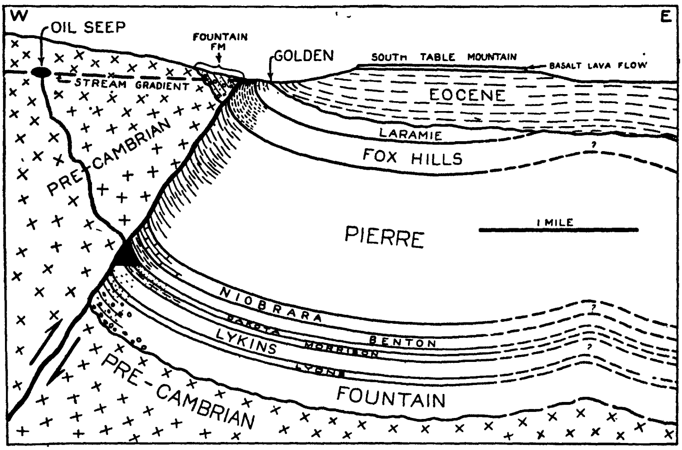

Fig. 205.—Thrust fault at Golden, Colo., showing the oil seep in Gold Run Canyon. (*After Irwin, Bull.* A.A.P.G., **10**, 111, Fig 2.)

from Gold Run Canyon 1½ miles north of Golden where oil comes out of pre-Cambrian gneiss. Obviously, the oil is not indigenous to this rock and must have reached the surface by following some crevice or series of crevices through the gneiss. A possible interpretation of the source of the oil is given in Fig. 205 taken from Irwin's excellent article on faulting in the Rocky Mountain region. This figure also shows the stratigraphic section characteristic of the eastern Colorado district, drawn to scale, as well as one of the thrust faults found along the Front range.

At Boulder, about 18 miles north of this locality, some drilling was done near an oil seepage many years ago. Oil in small quantities was discovered in the Pierre shale under very similar

conditions to those described for the Florence field. Fennemann[1] studied this region for the U. S. Geological Survey and found an anticline north of the developed area. This anticlinal area was then tested with favorable results and some fairly good wells were obtained, pumping from 5 to 170 barrels per day. The oil seems to occur in a sandstone within the Pierre shale at a depth of 2,000 to 2,500 feet and has a gravity of 40° Bé. At present, the production from this pool is very small, and averages about 25 barrels per day. The grand total of the pool from the beginning amounts to less than 500,000 barrels.

Green River Basin.—The Green River basin, described in considerable detail in the section on Wyoming, extends down into Colorado for some distance as shown in Fig. 184, p. 454. It will be noted that the south boundary of the basin is the Uinta Mountain range and its continuation toward the southeast, where it connects with the Rocky Mountain ranges. In the Uinta range a thrust fault from south to north has pushed Cambrian and pre-Cambrian sediments up over Cretaceous rocks. This overthrust may be clearly followed as far as Vermillion Creek which flows south across the mountains not far east of the boundary line between Colorado and Utah. From there toward the east it is obscured by Tertiary rocks. The axis of the Uinta Mountains lies about 10 miles south of the faulted zone and may be traced by means of inliers of old rocks as far as a point 15 miles south of Craig in Moffat County. Its projected trace in this part of Colorado is called the Axial Basin anticline. Park range and its continuation in Wyoming, called the "Medicine Bow range," forms the eastern boundary of the basin.

In the southeast portion of this basin there are several domes which have produced commercial quantities of oil and gas. One of these lies 12 miles south of Craig and is called "Moffat" (formerly Hamilton) dome. It is not large, having a diameter of only about 2½ miles, is nearly circular in shape and has a closure of 800 feet. Seven miles southwest lies the Iles dome which has nearly the same amount of closure and is of nearly the same shape and size. It is faulted on the north side, a feature that has not been noted on the other dome. Oil was first found on the Moffat dome in 1923 at a depth of 3,800 feet and at Iles dome about a year later. More recently, oil has also been found at Tow Creek which lies north of the Yampa River between

[1] See Bibliography.

Hayden and Steamboat Springs. Gas has been found at Thornburg, 10 miles southeast of Iles, and in the Hiawatha dome on the Colorado-Wyoming line.

Generalized Stratigraphic Section for Green River Basin

System	Series	Formation	Thickness, feet	Character
Tertiary	Miocene	Browns Park	1,200	Sandstone, chert, and conglomerate
	Eocene	Bridger Green River	1,500	Clay, shale, marl, chert, limestone Grey shale and oil shale, some sandstone and limestone
		Wasatch	4,000	Variegated shales, limestones, sandstone and some coal
		Post-Laramie	800	Sandstone, shale, coal, conglomerate
Cretaceous	Laramie	Laramie	2,000	Sandstone, shale, some coal
	Montana	Lewis shale Williams Fork Iles formation	1,200 2,000 1,350	Grey marine shale, sandstone Sandstone, shale, and coal Sandstone, shale, and coal
	Colorado	Mancos shale	5,000	Mostly shale, some sandstone. Dark and black shale at base
	Dakota	Dakota	155 to 250	Sandstone shale in middle, conglomerate at base (= Cloverly)
Comanchean		Morrison	500	Variegated shale, thin sandstones
Jurassic		Twin Creek limestone Nugget sandstone	125 950	Thinbedded limestone, some shale Cross-bedded sandstone
Triassic		Ankareh shale Thaynes and Woodside	200 800	Red and grey shale, sandstone Mostly shale, some limestone and sandstone
Permian		Park City	115	Limestone, chert, sandstone, shale
Pennsylvanian		Weber and Amsden	1,500	Quartzitic sandstone, limestone, etc.
Mississippian(?)		Madison(?)	600	Limestone, some sandstone, and conglomerate
Cambrian(?)		Lodore	200	Red and green shale, sandstone, pink limestone, conglomerate
Pre-Cambrian		"Uinta" group	12,000	Red sandstone and quartzite

[1] After Sears in *U. S. Geol. Survey Bull.* 751, p. 277.

The generalized stratigraphic section given above will indicate what strata are encountered in the wells on Moffat and Iles domes and what may be expected in the rest of the basin. Most of the basin is covered with Eocene strata, but, in the southeast corner, the Cretaceous rocks crop out and the structure may be worked out very accurately. The Iles dome is practically on the axis of the Uinta Mountains as projected in the Axial Basin anticline, but the Moffat dome lies within the basin a short

distance. In the Iles dome there are three producing horizons—a shale zone 100 feet above the Dakota, the Morrison sand and the Sundance sand. In the Moffat dome the Dakota, Morrison and Sundance sands are productive. The production of the Moffat dome during 1929 was 435,000 barrels; of the Iles dome, 531,000; of Tow Creek, 170,000 barrels.

Uinta Basin.—Just across the Uinta Mountain range and to the south of the Green River basin lies the Uinta basin (see Fig. 184, p. 454). That portion which lies in Colorado has many indications of oil. The Nugget sandstone of Jurassic age is saturated with oil at a number of places. Sears reports one place in S. 6,T. 9 N., R. 100 W. In the same township, but in Sec. 23, the basal conglomerate of the Dakota formation is also saturated with oil. Even the Eocene strata seem to contain free oil in this part of the Rocky Mountain region, for on Whiskey Creek, which is very close to the state line and to the town of Dragon, Utah, Ball has reported that free oil exists in the Green River formation. The first and, up to the present, only commercial pool discovered in the basin, was located near the oil seepages. Across the state line, in Utah, near Soldier Summit, the largest ozokerite deposits known in the United States occur in the upper part of the Wasatch formation.

The Uinta basin is bounded on the north by the Uinta Mountains; on the east by the Rocky Mountains; on the south by the *Uncompaghre* plateau and *San Rafael swell;* and on the west by the Wasatch Mountains, which trend nearly north and south in Utah. It has a width, north and south, of about 80 miles, a length of nearly 240 miles, and an area of about 65,000 square miles. That portion of the basin which lies in Colorado is tectonically isolated from the rest of the basin by a number of small positive elements, and is called separately the "Grand River basin." Three anticlinal areas which trend nearly east and west lie across the basin very close to the state line and thus produce a north to south dividing ridge. The northern one of these anticlines has been named the Midland uplift by Gale. On it the Carboniferous strata are brought to the surface. The middle one, and the one which will be of most interest because of its oil pool, is the Raven Park anticline. South of it lies the Douglass Creek flexure, on which Mesaverde strata are exposed.

The Raven Park anticline is an oval dome with an axis trending northwest to southeast. The western end lies about on the

Colorado-Utah line and the eastern end terminates in the Cathedral Bluffs. On the northeast side of this anticline the strata dip 4 to 6°, but on the southwest side the dip is steeper and ranges from 15 to 35°. This anticline has the greatest areal extent of the three anticlines, but shows the least amount of deformation. Its area is approximately 250 square miles. On this anticline the Rangely pool is located (see Fig. 184). The first well was drilled in this pool in 1901 and it had a good show of oil at a depth of 750 feet. From then, until 1907, quite a number of wells were drilled, all of which had the best showings at from 400 to 750 feet. This zone of strata appears to belong to the Mancos formation and consists entirely of shale or possibly

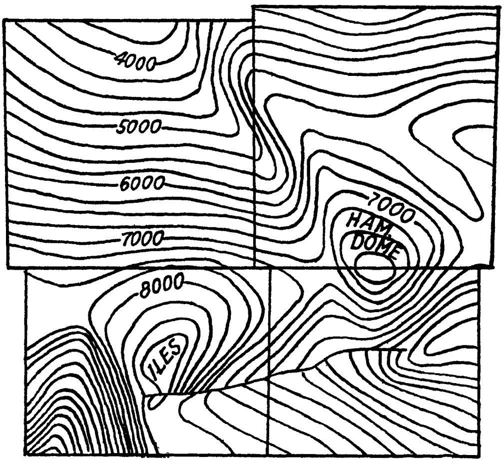

FIG. 206.—Geologic structure of Hamilton (now Moffat) and Sleeping Spring Gulch (now Iles) domes in Moffat County, Colo. (*After U. S Geol. Survey.*)

sandy shale. Studies by Sears in that region and adjacent areas lead him to believe that the producing zone lies about 1,900 feet below the top of the formation.[1] The oil has a gravity of 44° Bé. and the production, during the year 1927, amounted to 36,500 barrels. Some of this oil and much gas came from the Dakota at 3,740 feet, discovered early in 1927.

The only other oil pool developed in the Uinta basin up to the end of 1928 is the De Beque. This is also an old pool and was located because of the presence of oil seeps. It is shown on the map (Fig. 184) about 75 miles southeast of the Rangely

[1] *U. S. Geol. Survey Bull.* 751, p. 313.

pool in Mesa County. The first well was drilled in 1902 and found oil at the shallow depth of 614 feet in the upper part of the Mesaverde shale. Here again no sand is present and the oil seems to occur in the shale crevices and openings. The gravity of the oil is about 37° Bé. and the production has never been of much consequence. As regards relation to structure, Woodruff reports that an anticline extends westward from the pool for a distance of 8 miles or more and that the wells drilled up to 1904 were located not far from the crest of the fold. The rocks dip at angles of 3 degrees toward the south on the south side and at angles of 5 degrees toward the north on the other side.

In this basin 4 gas pools have been discovered which may lead to something important later on. They are the Rangely, White River, Carbonera, and Garmesa pools. The gas in the Rangely pool comes from the Dakota sand at a depth of slightly over 3,000 feet, and the potential acreage covers approximately 5,500 acres. The White River pool lies about 40 miles east of Rangely on the crest of a minor anticline which crosses the White River at this point. A gas seepage known from early times invited a test which found a strong flow of gas at a depth of 538 feet in the Wasatch formation. No further testing has been successful. The Carbonera and Garmesa gas pools are located in the southern part of the basin very close to the Utah state line and about 40 miles west of the old De Beque oil field. In the Carbonera pool, the Dakota was found at about 3,200 feet and the four wells drilled there are capable of producing 50,000,000 cubic feet of gas per day. In the Garmesa pool which lies 7 miles south of the Carbonera pool the producing horizon is also the Dakota sandstone. It is found at about the same depth and the production is estimated at 60,000,000 cubic feet per day. At present all the gas wells in the various pools described above are shut in for lack of a market. The location of these gas pools is shown in Fig. 184, p. 454.

Relation of Structure to Production in Colorado.—In the oil fields of the state of Colorado there are two very different types of occurrence. One of these types corresponds very closely to the usual and expected type in the Rocky Mountain province. It is the occurrence of oil and gas in the highest part of high domes and anticlines. Examples of this type of occurrence may be cited in the Fort Collins dome in eastern Colorado, the Wellington dome in the same district; the Moffat and the Iles domes

in the Green River basin. These are outstanding examples although in none of them has drilling proceeded to a point where the productive area is fully outlined. The closure on the domes cited varies from 350 to over 1,000 feet. No oil has been found outside of the lowest closing contour on any of these domes. Apparently, however, all similar domes are not necessarily productive as many operators have found out by drilling dry holes testing all sands down to and including the Dakota.

The second type of oil occurrence in Colorado is rather remarkable and worthy of careful study, for it may lead to the recovery of much oil in the future at unsuspected places. As has been shown above, oil and gas also occur at quite a number of scattered points in the state in shale, and apparently without the usual structural conditions which are expected to trap the fluids. At Florence, for example, the oil occurs in some kind of opening in the shales under monoclinal conditions. The openings in the shale may be enlarged stratification planes due to unequal subsidence of thick masses of shale in the deep Rocky Mountain trough; they may be more or less vertical crevices formed on account of slight compressional stresses or they may be openings of another kind due to an obscure cause. The drill does not solve this problem and we are forced to seek a solution on a more or less empirical basis. From a practical standpoint, a great deal of territory becomes open for future exploration along the Rocky Mountain front, because there great thicknesses of shale containing bituminous streaks and zones are present. The fact that production is likely to be small per well is offset to a partial extent by the long life of the wells and the absence of water troubles. Some expense is also saved in drilling costs because it is possible to carry an open hole without fear of water invasion.

In the *Rangely* pool the shale production is apparently located on an anticline, and the same is true at *De Beque,* and partly at *Boulder*. Whether the presence of the fold has had any influence on the accumulation of oil in these pools is problematical. The natural inference is that the anticlinal structure is probably a helpful factor. To what extent, however, it is impossible to state at present. A very careful study of the areas in which the oil is produced from shale is necessary before our knowledge can be as complete as it is now in regard to production from sandstone reservoirs.

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NOTE.—See also general reference list on Rocky Mountain province at end of chapter.

NEW MEXICO AND UTAH

Oil and gas in commercial quantities have been found in two widely separated parts of New Mexico. One of these areas has been described in a previous chapter (see p. 443) and the other will be described here since it properly belongs into the Rocky Mountain Petroliferous province. New Mexico has a central zone of ancient rocks which continue south from central Colorado. On the eastern side of this relatively high granitic and metamorphic complex the strata of Cretaceous and Tertiary age occupy the surface in a nearly featureless plain. West of the central mass in the northern part of the state lies a basin similar to those of Colorado and Wyoming which have been described. This is the San Juan basin and, according to Fig. 184, p. 454, it reaches over into Colorado and Utah a short distance. Like the other basins it is also a structural as well as a topographic basin,

containing the youngest rocks near the center and narrow bands or fringes of older rocks about the periphery.

On the east, the basin is bounded by the Rocky Mountains; on the northeast, by the San Juan Mountains; on the north, by the Uncompaghre plateau; on the west, by various small mountain uplifts and the uparched area in southeastern Utah. In New Mexico, it includes all of San Juan County which lies in the northwest corner of the state and portions of Rio Arriba and McKinley counties. Its area is not far from 140,000 square miles, if the Zuñi basin forming its southward continuation is included. An isocarb map prepared for this part of the state, by Storm, shows that it lies just within the 65 per cent deadline for oil pools. It may also explain why the gravity of the pools in that part of the state is as high as it is.

Oil Pools of the San Juan Basin.—The only commercial oil and gas pools in New Mexico are the Artesia field in the southeastern part of the state, described in Chap. IX, and the Hogback, Rattlesnake, and Table Mesa pools in the San Juan basin. The last three pools are all located close to the village of Shiprock in the northwestern part of San Juan County. Shiprock lies about 15 miles south of the Colorado line and about 25 miles east of the Arizona line.

The Hogback dome was the first to be drilled for oil. In August, 1922, the Midwest Petroleum Company brought in the first successful well on this structure. About two years later the Rattlesnake dome was found to contain oil and the Table Mesa dome was discovered in September, 1925. In the meantime, Tocito, which had been regarded as the best dome in the area, had been proved dry and, similarly, Beautiful Mountain dome and Biltabito had also been condemned by the drill.

Stratigraphy.—The stratigraphy of this part of the Rocky Mountain petroliferous province is very similar to that of the producing areas farther north, but different names are in use for the various formations. The section on p. 548 is taken from Darton's report on the geologic structure of parts of New Mexico.[1] The Eocene is here divided into the Wasatch, Torrejon, and Puerco formations. Of these names only Wasatch is used in the oil areas farther north. All three formations consist of clay, sandy shale, sandstones, and conglomerates. The total thickness is about 400 feet.

[1] *U. S. Geol. Survey Bull.* 726-E, p. 177, 1922.

STRATIGRAPHIC SECTION FOR SAN JUAN BASIN OIL POOLS1

System	Series	Formation	Thickness, feet	Character
Tertiary	Miocene	Santa Fé	450	Sand, gravel, silt, sandstone, and conglomerate
	Eocene	Wasatch	2,000	Conglomerate, sandstone, and shale
		Torrejon	400	Clay, shale, sandstone
		Puerco		Clay, shale, sandstone
Cretaceous		Ojo Alamo	65 to 110	Sandstone, conglomerate, and shale
		Kirtland	800 to 1,800	Shale with *Farmington sandstone* member
		Fruitland	190 to 290	Sandstone, shale, coal, and concretions
		Pictured Cliffs	200	Sandstone, copper-colored, etc.
		Lewis shale	200 to 1,200	Shale, greenish and sandy
	Mesaverde	Cliff House	400	Sandstone with some shale
		Menefee	800	Shale, sandstone, and coal
		Point Lookout	300	Sandstone with some shale
		Mancos shale	1,500	Shale with sandstone members
		*Dakota	75 to 125	Sandstone mostly massive and hard
Comanchean		Morrison	200	Shale and sandstone
Jurassic	La Plata	Navajo sandstone	600	Sandstone, massive, pink, etc.
		Todilto limestone	95	Limestone and gypsum
		Wingate sandstone	400	Sandstone, massive, pink
Triassic		Chinle	850	Shale mostly red
		Shinarump	50 to 120	Sandstone mostly coarse
		Moenkopi	400 to 800	Shale, mostly red and sandy
Permian	Manzano	Chupadera	600	Limestone, sandstone, and gypsum
		Abo sandstone	700	Sandstone red, some limestone
Pennsylvanian		Magdalena	2,000	Limestone, some shale, sandstone
Pre-Cambrian				Granite and schist

The Tertiary rocks crop out in the deeper portion of the basin in eastern San Juan County. In the western part of the county, where the oil pools are located, the Cretaceous rocks are on the surface. In Fig. 207 are shown a number of sections made of the Cretaceous rocks in the San Juan basin and two comparative sections at some distance east and west of it. Numbers 16, 17, 18, 19, and 20 are sections made within the confines of the basin. The section for Raton in eastern New Mexico is very similar to the generalized section for eastern Colorado (see p. 531) except that the Pierre shale is considerably thinner here. It will also be noted that the so-called "Laramie" formation of earlier writers has been replaced by the Ojo-Alamo, Kirkland, Fruitland, and Pictured Cliffs formations in the San Juan basin. The Lewis

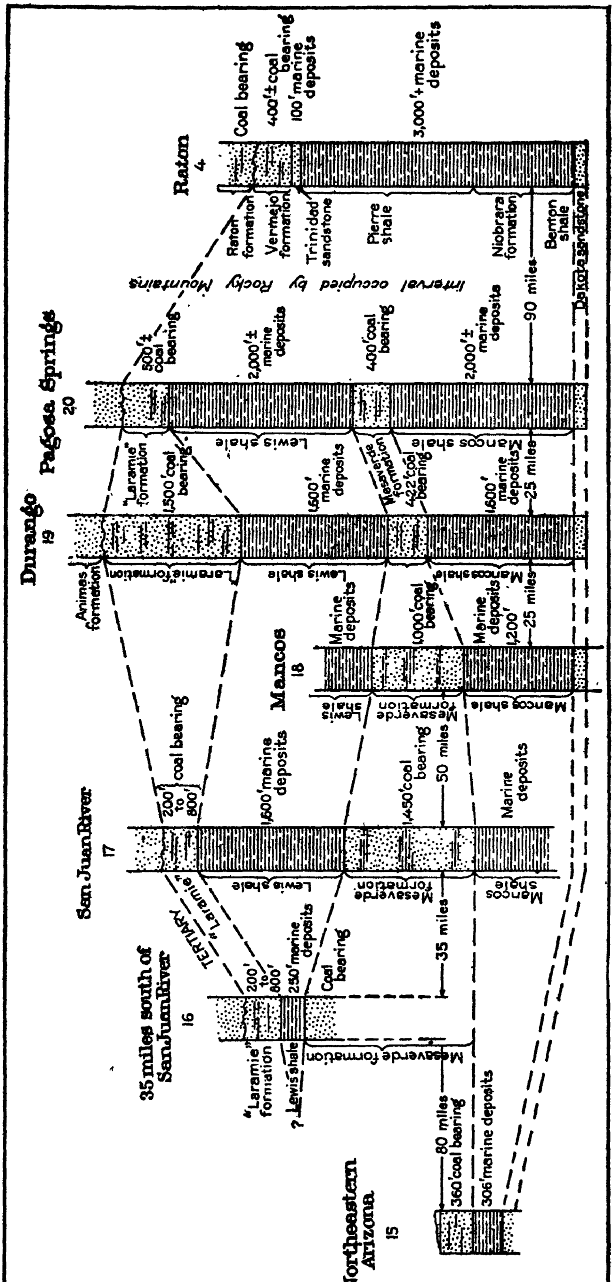

FIG. 207.—Group of sections from Black Mesa, Ariz., to Raton, N. M., across the San Juan basin. (*After Lee, U. S. Geol. Survey, Prof. Paper* 95, p. 48, Fig. 19.)

shale varies from 200 to 2,000 feet in various parts of the basin. The Mesaverde which is the coal-bearing portion of the Cretaceous also shows considerable variation in thickness from place to place. The Mancos shale is the most interesting formation because it is probably the source of most of the oil and gas found in the domes of this basin. It consists of marine shales containing many thick zones of dark-colored and black bituminous shale. At the base of the sections lies the Dakota sandstone, which is the most important formation, because it serves as reservoir rock for the oil and gas in this basin.

The material for the great thicknesses of Cretaceous rock came from the large continental mass which lay west of the present Rocky Mountains. This is indicated by the fact that the sandstones thin out toward the east (that is, toward the Rocky Mountains), and the shales thicken in that direction. The greatest thickness of sediments accumulated near the center of the basin which was just east of the present Rocky Mountain front in northern Colorado and southern Wyoming. The fact that the Cretaceous rocks occur in North Park (see Fig. 183, p. 453) at altitudes of 10,000 feet or more indicates that they were once continuous with rocks of the same age in the Green River and the Julesburg basins on both sides of North Park and at lower elevations. From these facts Lee concludes that the Rocky Mountains were not in existence at that time, but were formed after Laramie time.

Pre-Cretaceous Formations.—The formations which are older than the Cretaceous system have a good deal of interest to the petroleum geologist because many indications of oil have been found in these strata within and around the San Juan basin. At Boundary Butte, for instance, in southeastern Utah, 25 miles west of the New Mexico state line, a goodly amount of oil was found in the Shinarump sandstone. The Navajo and the Wingate sandstones have yielded shows of oil in deep wells in the basin. In the San Juan oil pool of southeastern Utah the oil is found in a sandstone in the Pennsylvanian system. Therefore, these sandy horizons are still looked upon as possible producing zones of the future. In fact, oil was found at 6,771 feet in a well on Rattlesnake dome in April, 1929.

Producing Horizons.—At present the only horizon which produces oil in large quantities is the Dakota sandstone. It is the productive horizon in the Hogback, Rattlesnake, and Table

Mesa pools. It is also the producing horizon of the Ute dome where it furnishes large amounts of gas. The Ute dome lies in T: 32 N., R. 14 W., a distance of about 15 miles northwest of Farmington or 25 miles northeast of Shiprock. Two wells in this dome are capable of producing 40,000,000 cubic feet of gas. In the Aztec dome which lies 15 miles southeast of the Ute dome, gas is found in the Farmington sand, a sandstone horizon in the Kirkland formation.

The *Dakota* sandstone in the San Juan basin consists of variable grey to brown cross-bedded sandstone with a cherty conglomerate at the base. It contains also lenses of shale and beds of impure coal. The thickness varies from 200 to 250 feet. On the Rattlesnake dome drilling has shown that it is present in three benches separated by thin shale zones. The oil is most abundant in the upper bench, but does not occupy the total thickness of this bench. The upper 7 feet of this pay zone is dry, the lower 20 feet carrying the oil.

Above the Dakota sandstone there is a thick zone of black shale beneath a sandstone called the *Tocito.* This thick bituminous shale zone constitutes the lower third of the Mancos shale and is probably the original source of the oil in the Dakota sandstone. One remarkable feature about the oil in this sandstone is the extremely high gravity. Rattlesnake dome contains the highest gravity oil in the United States and the other two domes carry oil which is not much lower.

The *Farmington* sandstone deserves some mention because it has been found to contain considerable quantities of gas in the Aztec dome on the east side of the basin. This sandstone lies near the middle of the Kirtland formation and was named by Bauer from its typical development near Farmington along the San Juan River. It consists of two parts, an upper indurated portion 15 feet thick and a lower unconsolidated portion 16 feet thick. All is cross-bedded and irregular white to brown sandstone. From its type locality it seems to thin toward the north and the south and probably does not correspond to any known member of the upper Cretaceous outside of the basin. The lower member of the Kirtland formation immediately below the Farmington sandstone contains a large amount of carbonaceous matter and is the probable source of the gas in the sandstone.

Relation of Production to Structure.—In the San Juan basin the same close relation of production to structure which is so

characteristic of the Rocky Mountain petroliferous province as a whole is found. In no case has oil or gas in large quantities been found except on the highest parts of high domes or anticlines. Five small domes have been found productive up to date. These domes have a closure of hundreds of feet in each case, but the productive area is much smaller than the entire closed area. For instance, on the Hogback dome the entire closed area amounts to about 18,000 acres, yet the productive area as defined by the wells drilled up to the close of 1928 is barely 160 acres and takes in only the highest part of the subsurface dome. Incidentally, the dome as shown by subsurface contours does not lie directly under the surface dome on any of the structures. On Rattlesnake dome the Dakota will be productive within about 60 feet of closure and the productive area will cover about 800 acres. The well which had the largest initial production came in for 800 barrels per day. Twenty-five wells had been drilled up to June, 1928. The depth to the producing horizon is about 800 feet on this dome which makes drilling expenses rather low. A deep test well found oil in Pennsylvanian strata at a depth of 6,771 feet in April, 1929.

The first well on the Table Mesa dome was brought in on Sept. 1, 1925, at a depth of 1,317 feet, from the Dakota sandstone. The gravity of the oil from this dome is 63° Bé., whereas that from Hogback is slightly lower or 61° Bé.; and the oil from Rattlesnake dome is considerably higher or 74° Bé. The pressure behind the oil appears to be hydrostatic.

Relation of Production to Carbon Ratios.—According to a map by Nowels, which shows the carbon ratios of the San Juan basin and adjacent portions of the state, the gas-bearing domes (see also Fig. 184) lie between the 60 and the 65 per cent isocarbs. The oil pools also lie within this belt, but closer to the 60 per cent line. The fact that the oil has such an unusually high gravity may be accounted for by this situation. A sample of the oil from the Rattlesnake dome, taken by K. B. Nowels, the supervising engineer of the U. S. Bureau of Mines, when the atmospheric temperature was 80° F., had a temperature of 32° F. and was boiling. The gravity at that temperature was 69.5° which corrected amounts to 73.4°. Naturally, such oil weathers rapidly despite the special precautions provided, such as aluminum painted vapor-proof tanks etc. Most of the boiling as the oil reaches the surface is due to the fact that the liquid butane

of which there is nearly 20 per cent by volume, changes to the gaseous condition. Nowels, reports that when the Rattlesnake crude is weathered and free from its dissolved butane it has practically the same gravity as that of the Hogback and Table Mesa crudes, showing at about 62° Bé. This might indicate that the latter crudes have weathered underground and within the producing horizon. A careful study of the crudes in the producing domes and the oil shows in the barren domes might lead to some enlightening conclusions regarding the origin of the oil and its transformation during and after migration.

The Mancos Creek structure in southwestern Colorado apparently lies beyond the 65 per cent isocarb and that fact may explain why only shows of oil were secured in the Mancos shale and none in the Dakota sand. It may also explain why no commercial quantities of oil have been found in southeastern Utah.

Production Statistics.—The importance of the pools in the San Juan basin from the standpoint of production may be judged by the figures below. For purposes of comparison the figures for the Artesia field in southeastern New Mexico are also included:

Daily Average and Total Production of New Mexico Fields

Pool	Daily average, 1929, barrels	Total, 1929, barrels
Hogback dome	500	122,000
Rattlesnake	1500	416,000
Table Mesa	150	230,000
Artesia	800	320,000

The gas discovered in the Ute and Aztec domes is not being used at present, because there is no market for large quantities of gas in northwestern New Mexico.

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NOTE.—See also the general reference list at end of chapter.

UTAH OIL PROSPECTS

At the present time there are no oil pools of importance in the state of Utah. Small amounts are being produced in the southeastern part of the state near Medicine Hat in the so-called "San Juan field" and small amounts have been found in quite a number of test wells. Besides these definite indications of the existence of oil, many seepages of oil and gas as well as asphalt rock and oil-saturated rock have been reported from various parts of the state.

Tectonics.—The state of Utah lies in the Great Basin region of the United States between the Rocky Mountains on the east and the coastal mountains on the west. Positive tectonic elements are revealed in the Uinta Mountains which trend nearly east and west in the northeastern part of the state, the Wasatch Mountains which trend nearly north and south in the north-central part of the state, in the San Juan River uplift which lies mostly in southeastern Utah, and in various smaller uplifts in the western part of the state, most of which trend north and south. Negative tectonic elements are present in the continuation of the Green River basin of Wyoming and Colorado (see pp. 540 and 542); in the Uinta basin which lies in the northeastern part of the state (see Fig. 184, p. 454) and in unnamed basins in the western part of the state.

Oil and gas have been found in some of these. The San Juan field is located on the San Juan River uplift in southeastern Utah. The good show of oil in the Cane Creek anticline is also located in this part of the state, but farther to the northeast and not very far from the town of Moab. Still farther north (in the Uinta basin) are located the Ashley and the Cisco domes, on which gas has been discovered. In the Salt Lake area in the north-central part of the state many seepages of oil have been found. Finally, in southwestern Utah, near Virgin City, four wells have been brought in which are capable of producing about 20 barrels of oil per day.

Southeastern Utah.—Eastern and southeastern Utah have been looked upon with favor by oil operators since 1908 when oil was first discovered in the San Juan field. Later, when a gusher was brought in on the Cane Creek structure at a depth of 2,028 feet in Pennsylvanian strata, it was considered as very definite evidence of the existence of large quantities of oil and gas in that part of the state. Much exploratory work has been done by geologists and much work has also been done by the oil companies who drilled test wells at critical points. The results up to date are inconclusive.

Stratigraphy.—The stratigraphic succession in this part of Utah has been described in a number of papers, all of which will be found listed in the bibliography at the end of the section. The Tertiary is represented by the Wasatch with a maximum thickness of 2,000 feet. The upper Cretaceous equivalents of the Laramie, Lewis, and Mesaverde are also found occasionally, but chiefly in the Colorado portion of the basin. As a rule, the Mancos shale is the youngest formation encountered in the southeastern part of Utah. The Dakota occurs in spots of small extent and has a maximum thickness of 180 feet. The Comanchean is represented by the Morrison beds consisting of red, grey, green, and purple shales with some interbedded sandstones and has a thickness of about 600 feet. The upper Jurassic system has been divided into three formations, the Summerville, Entrada, and Carmel formations and the lower Jurassic has been similarly divided into the Navajo, Todilto, and Wingate formations. The Chinle, Shinarump, and Moenkopi formations make up the Triassic as they did in the San Juan basin of New Mexico. The Permian and Pennsylvanian formations hold the greatest interest at present, because all of the important oil shows have been associated with them. They are the Cutler, Rico, and Hermosa formations. Their character and thickness are shown in the table on p. 556.

San Juan Oil Field.—About 20 miles west of Bluff, oil was discovered seeping from the sandstones of the Hermosa formation (there called the "Goodrich") in the bottom of the San Juan River between Medicine Hat and the mouth of Slickhorn Gulch.[1] Several other places in nearby canyons are reported to have similar oil seepages. These indications of petroleum led to drilling with the result that a gusher was brought in, during

[1] Miser, H. D., *U. S. Geol. Survey Bull.* 751, p. 140.

FORMATIONS OF THE MOAB REGION, UTAH[1]

System	Formation	Thickness, feet	Character
Creta-ceous	Mancos shale		Shale and sandstone
	Dakota	180	Sandstone and conglomerate
Coman-chean	Morrison	600	Mudstone and shale of various colors, sandstone near base
Jurassic	Summerville	50 to 100	Sandstone, red and shaly
	Entrada	300 to 400	Sandstone, cross-bedded and massive
	Carmel	35 to 125	Sandstone, thin-bedded, red. Some shale
	Navajo sand-stone	400	Sandstone, massive, cross-bedded, white
	Todilto	250	Sandstone and shale, mostly red
	Wingate	350	Sandstone, grey, massive, and cross-bedded
Triassic	Chinle	200 to 750	Mudstone and sandstone, red and green
	*Shinarump	0 to 200	Conglomeratic sandstone
	Moenkopi	0 to 600	Red, shale, sandstone, some thin lime-stone
Permian	Cutler	0 to 600	Arkose, sandstone, and conglomerate, mostly red
	Rico	0 to 600	Sandstone and shale, red and purple
Penn-sylvani-an	*Hermosa	800	Marine limestone mostly, some sand-stone

[1] After Baker, Dobbin, McKnight and Reeside in *Bull.* A.A.P.G., **11**, p. 787.

1908, at a depth of 225 feet. The production from this well was used to drill other wells, but no other gushers have been found and the total results up to date have been somewhat disappointing. The only notable production has been secured from a few wells near Medicine Hat and Goodrich. There is no record of the total production since the oil has been used locally. The gravity of the oil is 39° Bé. It is found in ten different sandstones of the Goodrich formations seven of which have received names. They vary from 2 to 30 feet in thickness but appear to be rather well cemented and with little pore space. The stratigraphic range of the sands extends from a zone lying 33 feet below the top of the formation to a zone lying about 361 feet below the top.

Miser's studies in this part of Utah have revealed the presence of quite a number of anticlines and synclines. The oil field is

located between two of the anticlines in the Medicine Hat syncline. Most of the wells lie from 1 to 3 miles west of the deepest part of the syncline and may, therefore, be said to lie on its flank.

Oil Indications in Other Parts of the State.—In T. 20 S., R. 21 E., about 35 miles east of the town of Green River (see Fig. 184), is a dome called the "Cisco anticline." On this dome, four wells have been drilled to the Dakota sand which was found at a depth of 1,950 feet. A large amount of gas under a pressure of 170 pounds per square inch was found in these wells and they are estimated to be capable of producing over 100,000,000 cubic feet per day. The Cisco dome is in the southern part of the Uinta basin and is one of a great many similar structures which line the border of the basin. Another dome on the north side of the same basin is the Ashley Valley dome. It lies just west of the Green River in T. 6 N., R. 22 E. One well on this dome has reached the Dakota sand and is reported to have an initial production of 20,000,000 cubic feet per day. The depth of the producing horizon is about 1,700 feet.

A very interesting occurrence of gas has been found on the Farnham dome, 15 miles east of Price, on the San Rafael swell. The gas is characterized by a very high percentage of carbon dioxide and nitrogen, these two making up 97 per cent of the total in the analysis. It also has a strong odor of hydrogen sulphide, but the amount of this gas by volume is only two-tenths of 1 per cent. The sand in which the gas was found lies at a depth of 3,100 feet and is believed to belong into the lower part of the Moenkopi formation of Triassic age. Calvert believes that the gas had its origin in deep-seated emanations and ensuing chemical reactions. The San Rafael swell is due to a large igneous intrusion and the Farnham dome on its flank may be due to a similar but smaller intrusion. On each flank of the San Rafael swell there is a major fault which may have furnished an avenue of escape for the gasses from the igneous rock at depth.

In the extreme southwestern part of the state, in Washington County, some oil has been found near Virgin City. On the strength of asphalt veins and similar indications of the presence of oil a well was drilled 2 miles northeast of Virgin City, in 1907. Despite only a small production in this well 15 others were drilled nearby with no better results. In 1918, drilling was again started and the old wells cleaned out. One of the new wells had a pro-

duction of 5 barrels per day and this with the three old producers brought the daily total to 20 barrels per day in September, 1920.[1] The oil horizon is a 1-foot bed of limestone at the top of the basal Rock Canyon conglomeratic member of the Moenkopi formation. On the outcrop of this bed, west of Virgin City, places may be seen where oil and sulphur water are seeping from this layer. Heavy oil occurs in the cavities of the overlying limestone also. The oil wells are located on a monocline which dips southwest at an angle of about 5 degrees. Very minute terraces and noses are present, but it is very doubtful whether these have had any influence on the accumulation of oil in this particular locality.

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[1] See Bibliography, *Bull.* 726, p. 95.

CHAPTER XI

THE PACIFIC GEOSYNCLINE PROVINCE

General.—The westernmost petroliferous province in the United States is the Pacific Geosyncline province. As the name implies, it lies close to the present border of the continent and in the area adjacent to the Pacific Ocean. The Pacific geosyncline was named by Schuchert[1] and it occupied that portion of our continental mass which lies west of the Cordilleran Intermontane geanticline. It was a narrow trough or rather series of troughs at least 2,500 miles long and lay for the most part northwest and southwest of the land mass of Cascadia. The only part of this geosyncline which has produced commercial quantities of petroleum up to the present time lies in southwestern California. Other parts of the geosyncline, however, have surface indications of oil and it is entirely possible that small areas will be found in the future which will produce a limited amount of oil and gas.

Oil Fields of California.—The map (Fig. 208) shows the location of the main producing fields in the state of California. Some of the most recent pools are not shown on this general map, but their location is indicated on the more detailed maps which appear in succeeding pages. The principal pools lie within seven counties: Fresno, Kern, Obispo, Santa Barbara, Ventura, Los Angeles, and Orange. They may be grouped into four districts because of the dominant structural features. The pools which lie in Fresno and Kern counties are in the San Joaquin valley and are, therefore, often referred to as the Valley fields. Most of the pools in Santa Barbara County lie in or close to the Santa Maria River and have, therefore, been grouped together under the name of the Santa Maria district. The productive areas in the next county to the east—Ventura—form a more or less isolated group with similar characteristics and are, therefore, called the "Ventura district." Finally, there are quite a number

[1] SCHUCHERT, CHAS., Sites and nature of the North American geosynclines, *Bull.* Geol. Soc. Am, **34**, 184–186, 1923.

of pools in Los Angeles and Orange counties which have a good deal in common structurally and stratigraphically. These pools will be described as units in the Los Angeles Basin district.

The distance from one end of the oil-producing territory to the other is over 225 miles and the width at its widest point nearly 90 miles. But a small portion of this 20,000 square miles has actually been developed up to date and the proved acreage at present is about 125,000 acres. Nearly half of this total lies within proved areas, but has not been drilled.

Seepages.—Practically all the pools discovered before 1900 were found in the vicinity of seepages of oil or near asphalt

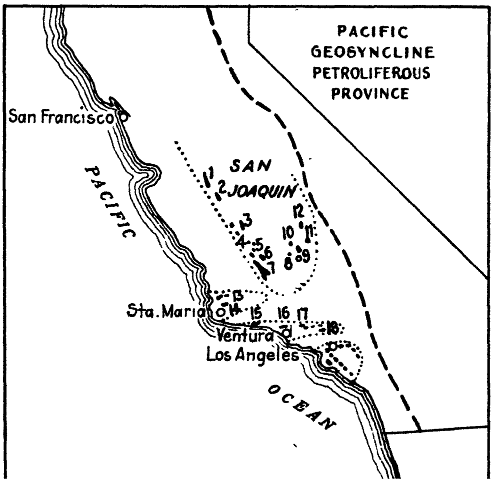

FIG. 208.—Pacific geosyncline petroliferous province. Districts outline by dots. Oil fields and pools in solid black.

deposits. The largest of such surface indications of oil are to be found in Ventura County. Some of the streams of tar near Sulphur Mountain are a quarter of a mile long, and a number of patches in the same general area are several acres in extent. In the San Joaquin Valley there are large seepages near Coalinga and near McKittrick. Some of the tar was removed in open cuts and from pits before any oil development took place. The pools discovered, since 1900, are mostly to be credited to the geologists employed by the oil companies operating in California or to those working for the U. S. Geological Survey. Among these pools may be mentioned Santa Fé Springs, Long Beach, Huntington Beach, and Torrance in the Los Angeles basin; Elk Hills, Lost

Hills, and Belridge in the San Joaquin Valley; South Mountain and Ventura Avenue in the Ventura district and all of the pools in the Santa Maria district.

Los Angeles Brea Deposits.—Perhaps the most interesting seepage area in California lies near the westerly limits of the city of Los Angeles. About 20 acres of land are covered with a rather stiff tarry substance (brea) which had leaked out of the oil-saturated sand and spread over the soil. In this asphaltum, Orcutt discovered the white bones, skulls, and vertebræ of prehistoric animals. These were taken to Stanford University for identification and later submitted to J. C. Merriam. He, recognizing the great value of the find, later secured a lease on 2 acres of the brea deposit for the purpose of securing additional specimens. Soon, other vertebrate paleontologists did the same; with the result that about 300 complete skeletons were removed from the asphalt. Among the animals represented in the unique collection were mastodons, elephants, bison, horses, wolves, foxes, saber-tooth tigers, and innumerable smaller animals. Although some drilling had been done in the vicinity of this deposit, it remained for E. L. Doheny to find the first commercial production. His first well was a shallow one and was drilled in 1893. During the succeeding 3 years many other wells were drilled with the result that the first period of big overproduction was brought upon the oil industry. Since the oil was heavy and fit for fuel only it stimulated the use of fuel oil to such an extent that the baneful results of overproduction vanished within a short time.

General Character of the California Fields.—The oil fields of California have certain characteristics which differentiate them from the oil fields in other parts of the United States. Some of these characteristics are similar to those of other provinces described in the preceding pages, but, taken as a group, the characteristics are distinctive. In the first place the oil is found almost exclusively in Tertiary rocks, the Pliocene series yielding most of the oil. According to a tabulation of the principal California oil fields made by Gester (see Fig. 209) no less than twenty-eight, or about 60 per cent, of the fields listed produce oil from strata of Pliocene age. In at least five of these fields, however, there is a lower oil horizon of probable Miocene age also. The Miocene strata produce oil in nine fields, the Oligocene strata yield oil in seven fields, and the Eocene is not productive in any field. The

TABULATION OF THE PRINCIPAL CALIFORNIA OIL FIELDS
THEIR STRUCTURE AND THE AGE CHARACTER AND THICKNESS OF THE SOURCE AND RESERVOIR ROCKS

	Type of Structure				Age of Reservoir Formation					Character of Reservoir Rocks			Age of Source Rocks						
San Joaquin Valley Fields	Anticline	Terrace or Monocline	Fault	Syncline	Pliocene	Miocene	Oligocene	Eocene	Cretaceous	Sandstone Sandy Shale	Fractured Zone	Approximate Thickness	Pliocene	Miocene	Oligocene	Eocene	Cretaceous	Source Rocks	Thickness
Coalinga																			
East Side	x			/		x			x	x		150 ±			x		x	Shale	1000
West Side		x				x				x		100 ±			x			-	750
Lost Hills	x				x	/				x		500 ±		x				-	2500
Belridge	x				x					x		200		x				-	3500
McKittrick		/	x		x					x		50-200		x				-	3000 +
Midway-Sunset																			
Buena Vista Hills	x				x					x		400		x				-	5000 +
Elk Hills	x				x					x		300-600		x				-	3000 +
Fellows		x		/	x					x		125-300		x				-	3000 +
25 Hill	x				x	x				x		150-400		x				-	5000 +
Maricopa		x		/	x	x				x		100-400		x				-	5000
Wheeler Ridge	x				x	x				x		200-300		x				-	2000
Kern River		x			x					x		100-300		x				-	700
Santa Barbara Fields																			
Santa Maria	x				x	x				x		50-400	x	x				-	4500
Casmalia	x		x			x					x	30-150	x	x				-	3000
Cat Canyon	x				x	x				x		25-200	x	x				-	4500
Lompoc		x			x							200	x	x				-	4000
Summerland	x									x		10-100	?	x				-	2000
Ventura Co. Fields																			
South Mountain	x						x			x		50-300				x		-	3000 +
Sespe	x				/		x			x		250-400				x		-	3500 +
Modelo	x					x	/			x		200 ±		x				-	2000 ±
Hopper Canyon	x					x				x		50-100		x				-	2000 ±
Ojai-Sulphur Mountain	x				x	/				x		25-100		x				-	1000 ?
Conejo			x			x				x	x	200 ±				x		-	?
Shiells or Shells	x						x			x		300 ±				x			3000 +
Torrey Canyon	x						x			x		50-150 +				x		-	3000 +
Bardsdale	x						x			x		100-300 ±				x		-	3000 +
Simi Valley	x						x			x		200 ±				x		-	3000 +
Eureka Canyon	x						x			x		100 ±				x		-	3000 +
Ventura River	x				x					x		100-300		x				-	3000 +
Newhall District																			
Pico & Wiley Canyon	x					x				x		200-800				x		-	1000 ±
Elsmere Canyon		x			x					x		300 ±		x				-	1500 ±
Southern Calif. Fields																			
Salt Lake	x		/			x				x		200-300 /		x				-	2000-3000
Los Angeles City	x					x				x		200-300		x			-	-	2000-3500 +
Merced Hills	x				x					x		1200 ±		x				-	-
East Whittier	x		/		x					x		200 +		x				-	-
Brea-Olinda	x		/		x					x		100-200		x				-	-
West Coyote Hills	x				x					x		600 +		x				-	-
Fullerton or East Coyote	x				x					x		400 ±		x				-	-
Santa Fe Springs	x				x					x		1300 ±		x				-	-
Richfield	x				x					x		900 ±		x				-	-
Dominguez & Athens	x									x		300-600 +		x				-	-
Signal Hill-Long Beach	x				x					x		1500 +		x				-	?
Huntington Beach	x				x					x		1600 +	x	x				-	-
Torrance-Redondo	x				x					x		100-350 +		x				-	? — ?
Puente	x				x					x		700 ±		x				-	2000-3000 +
Inglewood	x				x					x			x ?	x				-	-
Total Fields 47	38	6	3		28	14	7		1				7	35	2	9	1		

X = major condition / = minor condition

FIG. 209.—Tabulation of the principal California oil fields (*After Gester, Bull.* A.A.P.G., **10**, 894, Fig. 1.)

Cretaceous rocks produce oil only at one locality which is a very small and restricted portion of the Coalinga field.

The second characteristic which is distinctive is the nature and thickness of the reservoir strata. They are comparatively soft and poorly cemented sands having an enormous thickness in the agregate. Although the individual sandy layers rarely exceed 40 to 50 feet and the average thickness is only 10 feet, yet the total thickness of sands in the section makes the producing zones as much as 1,500 feet thick. The sands are interbedded with clays and shales, but a typical cap rock such as is present in other provinces is rarely found in California.

The third feature which is somewhat distinctive for the California fields is the fact that the strata involved in the stratigraphic section are strongly deformed. Everywhere the Tertiary strata are folded into anticlines and synclines in which the limbs dip at a comparatively high angle. Faults are fairly common, but because of the nature of the sediments are not always detected. They serve to increase the complexity of the structural relations. Overthrust folds and faults are known and from some districts overturned folds have been described.

Fourthly, the abundance and size of the surface indications of oil are unusual in this country. Oil seepages and tar beds are unknown in some of the other provinces studied, and where they are present they rarely form conspicuous features as they do in California. The reason for this lies partly in the nature of the sediments which are loose and largely unconsolidated, and partly in the fact that the rocks are greatly disturbed.

Finally, the fifth characteristic is the great concentration of oil in small areas. In some of the California pools oil is found throughout a thickness of strata totaling nearly 6,000 feet. Innumerable sands forming thick zones which show great oil saturation occur under a given lease and account for a very large per-acre production. Individual leases on which the production totals 300,000 barrels per acre are not unknown and whole fields average over 100,000 barrels per acre. The only other province where such figures are duplicated is in the salt dome district of the Gulf Embayment province.

Tectonics.—The tectonic conditions which control the structural conditions found in the oil fields of California have been very well discussed by Bailey Willis.[1] He states that the pre-

[1] See Bibliography. See also paper by Bruce Clark.

dominant tectonic element is the shear as contrasted with folds in the Appalachians and other provinces. In the Appalachians shearing is also present but was produced as a result of the development of a forcecouple as a feature of overturned folds. They are thrust faults, many in number, but all related to a great master thrust plane which underlies the whole Appalachian geosyncline. This great thrust or sole underlies the whole eastern United States and accounts for a shortening of the earth's crust of at least 65 miles. The direction of movement in these overthrusts is up the dip of the fault plane which lies at an angle of about 35 degrees. Folding, however, is the dominant element in the structural deformation of the Appalachians and the thrusts are merely incidental. Long, well-developed anticlines and synclines in parallel alignment, strike the observer as the characteristic surface expression of the great crustal changes which have taken place. But folding is due to horizontal compression in a stratum which is strong enough to support the load which it lifts. It is only when bending and lifting become more difficult than shearing that the latter type of deformation develops. It thus becomes a function of depth as well as of homogeneous resistances and in sedimentary rocks it becomes easier than folding at a depth below 5 or 6 miles. In the Appalachians, therefore, Willis believes that we are dealing with a thin wedge whose bottom surface slopes from the Cumberland Plateau eastward under the Piedmont Plateau and the Coastal Plain deep down under the Atlantic basin.

In the Coast Ranges of California a very different set of tectonic conditions is present and, consequently, the structural features in the mountains as well as adjacent to the mountains is very different. Instead of the long, narrow, parallel structures so characteristic of the Appalachians, the folds in the Tertiary rocks are short, local, and often terminated by faults. This is primarily the result of the fact that shearing has been dominant and folding has been incidental. The reason for this lies in the presence of great batholiths in the foundations of the Coast Ranges and the Sierra Nevadas. The two batholiths were subjected to horizontal pressures also, but found it easier to break than to bend, and, in so doing, another fundamental difference was manifested. The faults produced by the shearing stand practically vertical at their outcrops instead of at a low angle as in the Appalachians.

The pressure in California appears to have been directed in a nearly north to south direction producing theoretically two sets of shears. One of these, the set trending from southeast to northwest, became active, while the opposite set became absorbed by a greater resistance. The faults thus produced are exemplified by

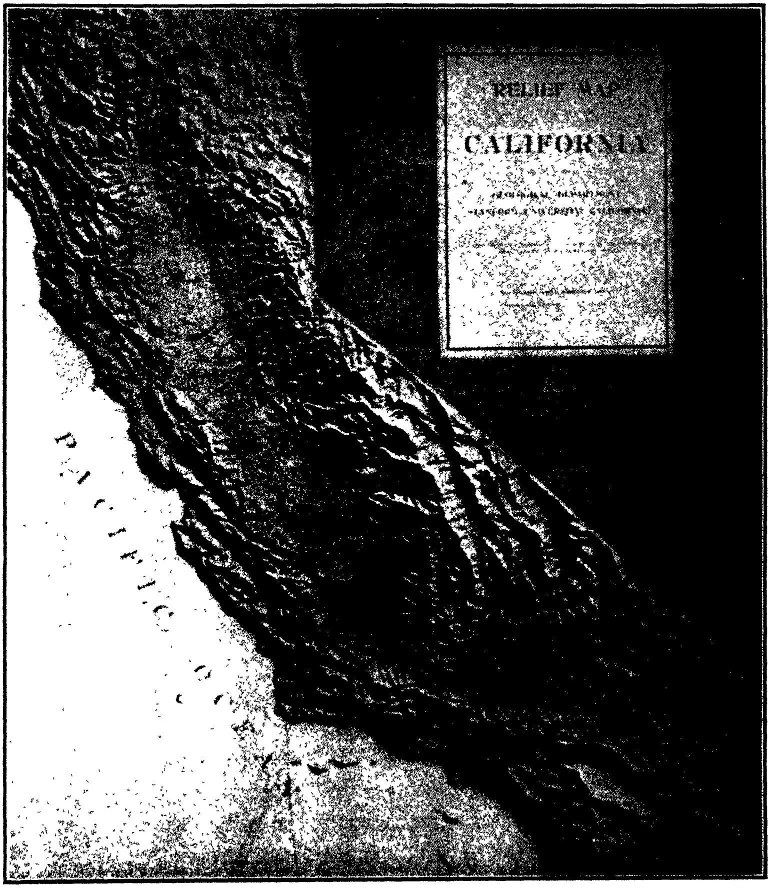

FIG. 210.—Relief map of California. (*After U. S. Geological Survey.*)

the San Andreas rift which is probably the longest shearing plane yet discovered (Fig. 212). It has been traced a distance of 600 miles from the Mexican boundary to Punta Arenas, on the coast of northern California. Fault planes and shear planes parallel to and similar to the San Andreas rift have produced a mosaic in the basement rocks in which the blocks range from 10 to 30

or more miles in length and from 4 to 15 miles in width. Actual movements of these blocks in recent times have been proved by observations of the U. S. Geodetic Survey. For instance, Mount Tamalpais near San Francisco moved toward the southeast from 1854 to 1906 a distance of 5 feet. Loma Prieta, a peak in the Santa Cruz Mountains, moved in the same direction about 16 feet in the same length of time. An interesting case in point is that of the Santa Ynez Mountains which trend nearly east and west between the Santa Maria and the Ventura districts (see Fig. 210). This range is bounded on the north and south by faults dipping about 70 degrees under it. The block is 75 miles long and 4 miles to 10 miles wide. Willis believes that pressure directed from southwest toward northeast caused the mountain block to move 24 feet northward in the last 30 years.

Shearing, which began in the Jurassic period, continued with interruptions of greater or less length right up to the present time. It affected the structure of the Sierra Nevada Mountains, the Coast Ranges, and the Basin ranges. During a large portion of the elapsed time sedimentation was going on in the straits and sounds which existed from time to time. Since the position of these varied, the thicknesses and stratigraphic sequence on each block differ greatly. The sediments consist of clastic materials, mostly, which are rather loosely cemented. The result of horizontal displacement along shear zones in the basement rocks on such sediments is interesting and of importance in reaching a correct fundamental concept in regard to the structural conditions in the oil fields of California.

Folding which results from such movements is directly the result of horizontal compression, but indirectly the result of the opposed movements in the unyielding rocks below the Tertiaries. Two kinds of folds result. When faulting takes place at depth, the effect of horizontal displacement is manifested in the formation of small anticlines above the shear zone, each of which trends at a small angle to the trend of the shear zone. This is illustrated in the line of anticlines along the southwestern side of the Los Angeles basin (see Fig. 226). When the fault reaches the surface, as for instance, in San Pedro Hill, which lies in the southwestern part of the same basin, a similar anticline results, though in a somewhat different manner. The strata in San Pedro Hill were dragged up along the fault which runs along the northeast side of the hill. Compression on that side has produced a syn-

cline adjacent to the hill and an anticline beyond that area. The latter is the location of the Torrance oil pool. Similarly, Willis believes that the domes and anticlines which constitute the Santa Fé Springs, Coyote Hills, and Richfield oil fields resulted from compression combined with drag along the adjacent Puente Hills fault. As the block southwest of the fault moved northwestward past the block on the other side, pressure perpendicular to the fault plane produced a resultant pressure directed toward the south. The strata were compressed in that direction producing short anticlines trending east and west.

Producing Horizons.—In California, the horizons which produce oil are soft sands, as a rule. These sands are interbedded with shales and clays and the individual layers are rarely very thick. As a general rule, many sands appear in the section close together making up what is termed a "zone of production." Such zones may be very thick and 1,500 feet of rock in one zone is not unheard of. Within the zone the sands are very lenticular so that no two well logs agree, except for the average thickness of the zone and its relative position to other zones. The zones may be separated by clays and shales or by other zones which are exactly similar in lithologic character, but contain water instead of oil, or are barren for some reason not clearly understood. A cap rock such as we are accustomed to expect in the petroliferous provinces of the eastern part of the United States is rarely if ever present.

Exceptional conditions for oil reservoirs exist in the Santa Maria pool where considerable oil has been produced from fractured shale of Miocene age. A still more interesting occurrence is that of the Conejo pool in the Ventura district where the oil has collected in a basalt agglomerate.

All Tertiary series with the exception of the Eocene have furnished or are furnishing oil at present. The Pliocene series leads when the number of pools is used as a basis of comparison, for it produces the oil in 28 of the 47 pools listed by Gester (see Fig. 209). Nearly all pools in the Los Angeles basin district derive their oil from Pliocene rocks and the same is true of the pools in the San Joaquin Valley district. In the latter district, the Miocene also produces in three of the pools and in two others it is the only source. In the Santa Maria district honors appear to be evenly divided between the Pliocene and the Miocene, but in point of the quantity Pliocene leads. In the Ventura district,

the Pliocene produces the oil only in two fields, but one of these, the Ventura Avenue, is by far the largest pool in the district.

The Miocene series is the only producing horizon in nine pools, but produces a part of the oil in five others. It stands second at present both in the number of pools and in the total of oil produced. Recently it has been found to be very prolific in some of the pools of the Los Angeles Basin district, where deeper drilling has reached the Miocene strata. It, therefore, threatens to rival the Pliocene in the future. The Vaqueros member of the series would seem to be an ideal oil reservoir, yet it is very frequently found to be barren or water bearing.

The Oligocene series is the chief producing horizon in the pools of the Ventura district with the exception of the Ventura Avenue pool. It is not known to be productive in any other district at the present time. No oil is found in commercial quantities below the Oligocene series with one small exception. This exception is a restricted area in the east side pool of the Coalinga field.

Correlation of Producing Horizons.—Correlation of producing horizons which is possible in most of the other provinces studied (and sometimes from one province to another) is practically impossible in the California fields. For that reason names of sands such as are used in the eastern part of the country are not necessary. Sometimes the zones in a given pool or field are named and these zones are traceable from well to well, but not from pool to pool.

The lack of key horizons in the California fields has hampered preliminary geologic investigations very much, but after a pool is once proved, the oil-saturated zone is used as a key horizon. In order to overcome the difficulty of finding usable horizons with easily recognizable lithologic characters for preliminary geologic investigations, much time has been spent on the mineralogical composition of the surface formations. Reed and Bailey[1] have shown that within a restricted area structural conditions can be worked out on the basis of the heavy minerals present in surface or shallow sediments. Hoots[1] made a special study of the southern end of the San Joaquin Valley to determine the usefulness of heavy mineral determinations. He concludes that sediments derived from a single land mass of comparatively uniform character may show distinct stratigraphic variations in the heavy

[1] See Bibliography.

mineral assemblages. Possible causes of variations are given as (1) source rock; (2) climate, altitude, and topographic changes; (3) distance and rate of travel of the fragments; (4) conditions of alteration after deposition. Correlation by means of microfossils has also been attempted. This method has met the same difficulties which were encountered in other provinces, namely lack of fundamental data for guidance and the similarity of the organisms throughout great thicknesses of strata.

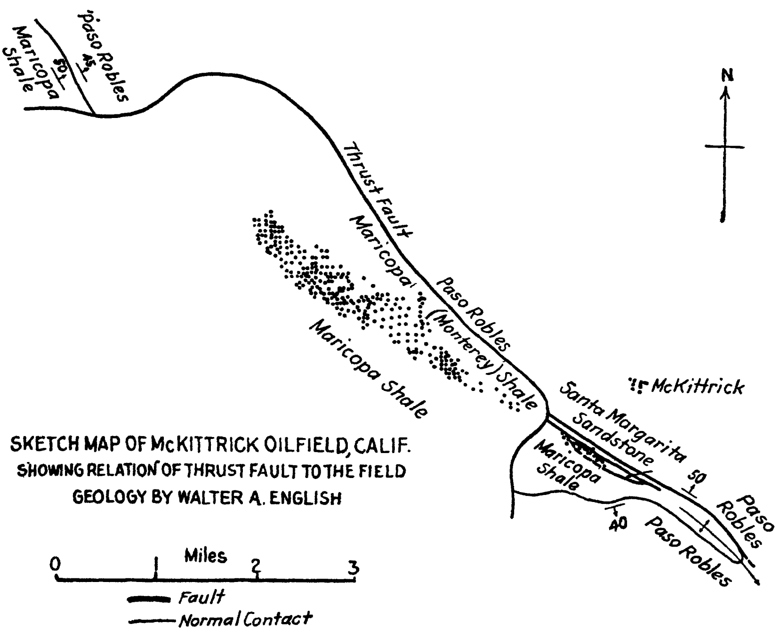

FIG. 211.—Sketch map of the McKittrick oil field, showing the relation of the thrust fault to the field. (*After English, Bull.* A.A.P.G., **11**, 618, Fig. 1.)

Relation of Structure to Production.—The table (Fig. 209), page 562, prepared by Gester, shows that 38 out of 47 pools listed produce oil from an anticline or dome, six produce oil from a monocline or terrace, and three produce oil from a trap due to faulting. The last type of trap is also given as a minor cause of accumulation in the case of three other pools. It will thus be seen that the anticlinal trap is by far the most important in this province and that the relation between structure and production is a very close one. With the exception of the west side of the Coalinga field all pools

in which the accumulation has taken place on a monocline are small or insignificant. The pools in which a fault appears to have trapped the oil are also unimportant with the exception of McKittrick. In the last-named pool there is considerable room for argument as to the exact structural conditions under which the oil accumulated. Figure 211 is a map showing the relation of the thrust fault to the location of the producing wells. English believes that the thrust fault simply serves to obscure the significant structure and that the controlling structure really lies below the fault plane. It is unlikely that this will ever be worked out because the field is an old one and the logs either lost or very poor.

Source Rocks and Migration.—As early as 1867 or about the time the first well was drilled in California, J. D. Whitney suggested that the "infusorial" shales of the state were the original source of the oil found in the seepages. Since Infusoria at that time included diatoms he evidently referred to the Monterey shale which is so rich in diatoms that it is often called diatomaceous shale. Later, workers in the oil districts also believed that the Monterey shales were responsible for the oil. Among these may be mentioned Arnold, Anderson, and Pack, to whom we owe the excellent descriptions of the earlier pools in the San Joaquin and Santa Maria districts[1] published by the U. S. Geological Survey. These geologists believe the diatoms and the foraminifera which were so numerous in Miocene time accumulated in such a manner that much animal tissue was buried with the tests and that this animal matter was converted into petroleum. Stipp[1] states that it is doubtful whether much animal tissue was buried with the tests, basing his statement on the findings of Cushman that the tests are usually empty when accumulating. Cunningham[1] also questions the validity of the assumption that diatoms are an important source of petroleum. He believes, however, that the organic matter in the Miocene shales is the probable source of the petroleum. Gester goes into the problem more thoroughly than any of the predecessors and concludes that the assumption, that the diatomaceous shale is the source of the oil, is merely taken for granted and still remains to be proved.

Shales are always associated more or less intimately with the oil-bearing horizons in California. This suggests the likelihood

[1] See Bibliography.

of the oil having originated in the shales. But the shales in the Tertiary section may be of Pliocene, Miocene, Oligocene, and Eocene ages and all of these have been looked upon as the source rock for oil in various pools of the province. The Miocene shales stand out more prominently than the others because they are associated with the producing horizons more frequently than the other bodies of shale. Gester states that some of the white-to-light-yellow diatomaceous shale, coming from an oil field area, was found to contain *not a trace of oil* either by solution or distillation test. Numerous tests made by him on the heavier, yellow-to-brown shales also showed no trace. It would be remarkable, indeed, if the whole of the original hydrocarbon content was removed when the oil accumulated. Some shales of a chocolate or dark-brown color were examined. These did give off oil by distillation and showed abundant carbonaceous or hydrocarbonaceous material under the microscope, but they did not contain diatoms or foraminifera in abundance. This seems to raise the question whether or not the diatoms are merely incidental or whether they contributed to a large extent to the original matter from which the oil was evolved.

As regards migration the conditions are very different in California from those studied in other provinces. Not only are the sediments very porous and loosely cemented, both of which are factors that promote easy migration, but the well-established presence of numerous faults indicates another avenue of easy migration. It should, therefore, not be surprising that most of the oil has accumulated in the Pliocene strata, regardless of the original source of the oil. The Pliocene series provides the most layers suitable for reservoir rock and the greatest thicknesses of such rocks. It is also the highest and last series capable of trapping and storing large quantities of oil.

Production Statistics.—The earliest production of oil came from the Ventura district and, up until 1894, no other district or pool except the Fullerton pool produced commercial quantities of oil. In 1894, Summerland and the Los Angeles City pools started to produce oil. Two years later, the Coalinga pool in the San Joaquin Valley began production for that district. Still, up to the end of the century scarcely 30,000,000 barrels of oil had been produced. In 1902, production figures started to mount more rapidly and, by 1914, the annual production reached 100,000,000 barrels. In 1923, which has been the banner year

up to this time, the total for the year was 263,000,000 barrels. All fields in California up to the end of 1929 have produced slightly more than 3,300,000,000 barrels.

The field which has accounted for the largest proportion of this total is the Midway-Sunset field with the remarkable amount of 668,000,000 barrels. No other field even approaches this total. The next in rank is the Long Beach pool with 382,000,000 barrels, followed closely by the Coalinga pool with 312,000,000 barrels and the Kern River pool with 275,000,000 barrels. Besides these pools six others have produced more than 100,000,000 barrels each.

The production per acre has also been phenomenal in a number of the pools of this province despite the fact that most of them are still young. When the total ultimate figures are available many of the pools will probably outrank any others in the world. Long Beach at present has produced 174,000 barrels per acre and Sante Fé Springs probably ranks second with about 100,000 barrels to the acre. The field with the largest production—the Midway-Sunset—shows a recovery per acre of only 15,000 barrels. This is explained partly by a difference in the thickness of the producing horizons and partly by the spacing of wells. In the Long Beach pool one well has been drilled for every 2 acres of proven territory, whereas in the Midway-Sunset field there is one well for every 18 acres. These figures may be compared to an average of about one well to 8 acres in the older

TABLE OF PRODUCTION STATISTICS

District and pool	Proven acreage	Recovery per acre, barrels	Total production, barrels, to January, 1930
San Joaquin Valley:			
Coalinga	16,500	18,684	312,000,000
Lost Hills-Belridge	4,600	12,675	60,000,000
McKittrick	2,000	40,000	77,000,000
Midway-Sunset	45,000	16,000	688,000,000
Elk Hills	5,000	20,000	110,000,000
Wheeler Ridge	225	8,000	2,000,000
Kern River	9,000	30,000	275,000,000
Fruitvale	100	8,000	842,000
Santa Maria district	9,000	15,000	125,000,000
Ventura district:	6,000	18,000	150,000,000
Ventura Avenue	2,500	33,000	85,000,000

pools. In the table on p. 572 all pools with the exception of those in the Los Angeles Basin district are listed showing the total production up to January, 1930, and the proven acreage in each. The pools in the Los Angeles Basin district are listed separately on page 617.

THE SAN JOAQUIN VALLEY DISTRICT

Introduction.—The San Joaquin Valley lies in the central part of the state of California and occupies the southern half of a large structural depression drained by the Sacramento and San Joaquin rivers through the Golden Gate. It is shown in its structural setting in Fig. 210, page 565, and is shown again in its relative position to the other districts of the state in Fig. 208. The individual pools named in order from northwest to southwest and then around to the east are the Coalinga, Kettleman Hills, Lost Hills, Belridge, McKittrick, Midway-Sunset, Elk Hills, Wheeler Ridge, Kern River, and Fruitvale pools. They occupy an area 150 miles long and 60 miles wide, but only a small percentage of the total acreage involved has been found productive. Many new fields are likely to be discovered in this district during the future.

The first field to produce was the McKittrick pool where oil was discovered as early as 1884. Three years later, production on a commercial scale began at McKittrick and, during the next 2 years, the success of this pool caused many test wells to be drilled in the Valley district with the result that Coalinga was opened up in 1890, Kern River in 1889, and Midway-Sunset in 1891. Lost Hills furnished its first oil well in 1910 and Belridge was discovered 1 year later.

Tar springs and oil seeps guided the first test wells in this part of the state as they did elsewhere. At Coalinga such seepages occur mainly in the Eocene and Miocene rocks especially along the line of unconformity between the two. These seepages were known long before oil operators became interested in the region. Again, west of the town of McKittrick enormous deposits of asphalt, formed at the point where the producing horizon of the McKittrick pool reaches the surface, were mined a long time before any attempt was made to drill for oil. Similarly, oil seeped from the ground west of the Sunset pool in the foothills of the Temblor Range and was mined as early as 1891, although no drilling was done in the pool until 1900.

The production of this district, since 1896, has been truly phenomenal. In 1896, Coalinga produced a little over 14,000 barrels of oil, but, by the close of 1929, this pool had produced a total of over 300,000,000 barrels. The largest total production has come from the Midway-Sunset pool which has accounted for 668,000,000 barrels. During the same time McKittrick produced 75,000,000 and Kern River 275,000,000 barrels. Elk Hills, which

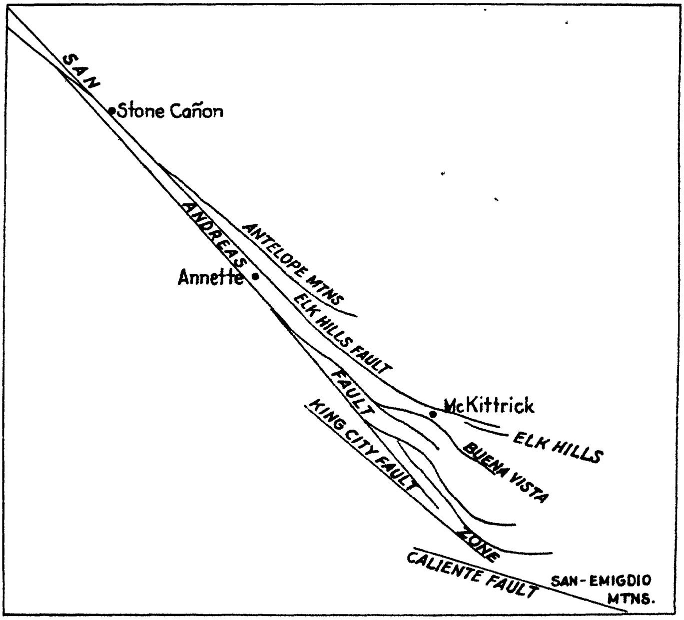

FIG. 212.—Details of San Andre's fault zone from Stone Cañon to the San Emigdio Mountains, a distance of approximately 100 miles. (*After Clark, Bruce, Bull.* A.A.P.G., **13**, 209.)

began in 1919, produced almost 100,000,000 barrels up to the end of 1927. Thus the total for the whole district amounts to 1,250,000,000 barrels.

Tectonics.—As the map (Fig. 210) shows, the San Joaquin Valley is a prominent structural depression between the Coast Ranges on the west and the Sierra Nevada Mountains on the east. These two positive tectonic elements trend in a general way from northwest toward the southeast. One of the offshoots of the Sierra Nevada Mountains, the Tehachapi Range, swings in a large arc toward the southwest and toward the coast making a closure for the depression at the southern end. According to

the stratigraphic record as shown in these mountains this closure occurred in Pliocene time.

In the San Joaquin Valley there are two main types of oil-producing structures: anticlines and monoclines. The greatest accumulations seem to occur in folds along the western side of the basin. These folds are subparallel to the trend of the mountain ridges in the Coast Ranges. Folds are also present on the western side of the valley. These folds differ in their origin, the folds along the west side of the valley being due to compression and the folds along the east side of the valley being due to vertical pressure. When the folds along the west side were formed, it may be assumed that a movement in the basement rocks took place in which the block on the southwest side of the shear zone moved northwestward with reference to the block on the other side. The pressure perpendicular to the fault plane combined with the drag to produce a resultant pressure, directed toward the north and northeast. Thus the folds developed in the Tertiary rocks with a trend usually from northwest to southeast, but often nearly east and west.

The folds along the east side of the valley were produced by vertical uplift,[1] this effect being due to movement in the deep-seated mass. When vertical elongation takes place as a result of horizontal compression in the zone beneath the stratified rocks, the superincumbent strata are arched up. If faulting should accompany the folding it is normal faulting and not thrust faulting as in the case of folds produced by horizontal compression. The whole structure is therefore under tension and open upward. This applies to the western side of the Sierra Nevada Mountains and the adjacent strip of the valley from the Kern River pool north.

Pre-Tertiary Rocks.—The stratigraphy of the southern end of the San Joaquin Valley corresponds rather closely to the topography. The mountain ranges consisting of the Sierra Nevada Mountains on the east, the Tehachapi Mountains and the San Emigdio Mountains on the southeast and the south, and the Temblor Range on the west consist for the most part of the oldest rocks. The foothill belt, which is quite narrow as a rule, consists of upturned Tertiary strata. This is the zone in which the oil fields occur and, therefore, the one which we shall describe in greater detail. Finally, the valley basin proper consists

[1] See Willis, Bailey, *op. cit.*, p. 41.

chiefly of very young, flat-lying alluvial deposits which form a blanket over the disturbed Tertiary rocks.

The oldest rocks crop out in the southeast part of the region and consist of mica and hornblende schists and crystalline limestone. They are thought to be of Paleozoic age. Intruded into these and much more prominent because they cover a much larger area are the granodiorite and granite masses, portions of the batholiths. These intrusions are believed to be of Jurassic age. They crop out close to the border of the valley on the east, southeast, and south sides, in some places coming abruptly against the flat-lying beds of the valley. In the Temblor Range which forms the western border of the valley, the Tertiary cover still conceals the granodiorite except in a few scattered places.

Another series of rocks consisting of highly altered sediments is the *Franciscan* series or formation. It crops out in small somewhat detached areas, especially in the Diablo range west of the Coalinga field. The most distinctive rock of this series is serpentine, but glaucophane, actinolite, and other schists are also present. The original sediments were sandstone, shale, and jasper and in some places such sediments are still to be found intimately associated with the more metamorphosed materials. Since no fossils have been found either in this district or elsewhere in the Franciscan rocks, they cannot be assigned definitely to a position in the stratigraphic sequence. They are pre-Cretaceous and probably Jurassic in age.

Next in the succession of rocks is a thick series of strata consisting of sandstone, shale, and conglomerate which are generally considered the equivalent of the Knoxville-Chico beds farther north. A few fossils found in the Devil's Den region establish the age of a portion of this section as Knoxville. The total thickness of the strata is in excess of 12,000 feet. The Tejon formation of Eocene age overlies the Knoxville-Chico unconformably.

In Fig. 213 parallel geologic columns have been plotted to show the change in thickness of the Tertiary rocks from field to field in this district. It also shows the position of the oil-bearing horizons.

Inasmuch as no single formation in the Tertiary sequence is continuously exposed around the valley and especially since the lithologic character of the formations changes so greatly from place to place it is scarcely necessary to describe the formations

for the district as a whole. Clastic materials such as sand, clay, shale, and sandstone with occasional gravel or conglomerate layers make up the complete succession of thousands of feet of

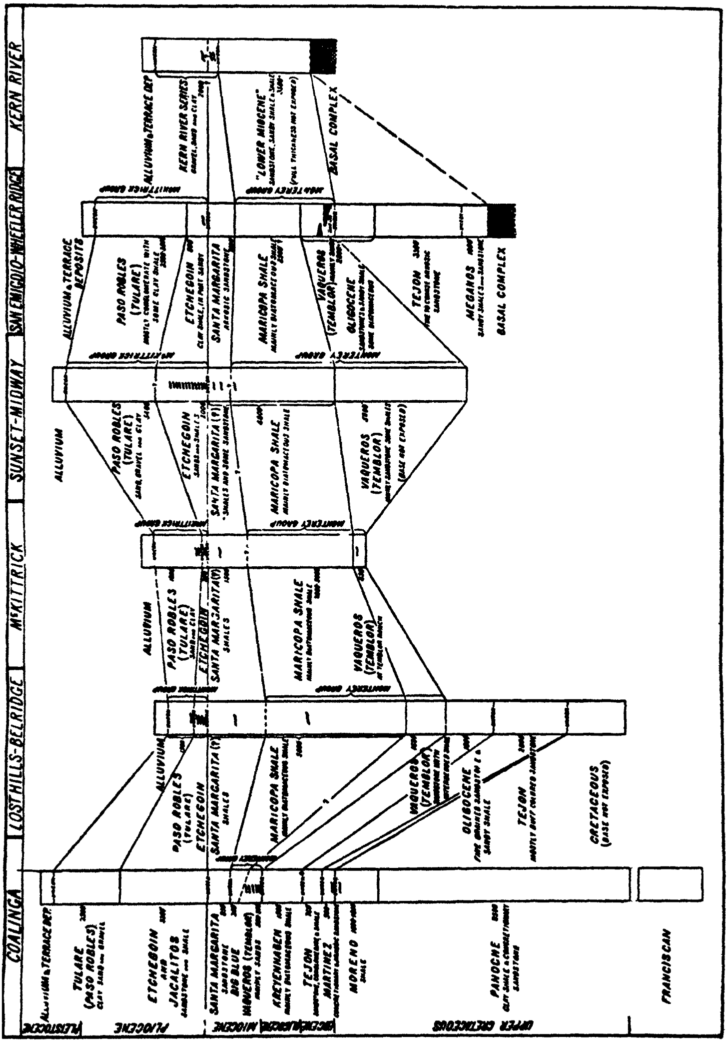

FIG. 213.—Thickness and correlation of the strata in the oil fields of the San Joaquin valley district. (*After Stevens, Bull.* A.A.P.G., **8**, 33, Fig. 3.)

strata. Sometimes lithologic peculiarities such as diatomaceous shales or foraminiferal shales or perhaps shales of unusual color appear in the section locally and make correlations possible. Again limy layers or impure limestones or perhaps cherty layers

are present locally to create a variation in the monotony of shales and sandstones ordinarily present. Further details regarding the stratigraphy will therefore be included under the description of the individual pools and fields.

All series of the Tertiary system are represented in the district under discussion from the Eocene at the base to the Pliocene at the top. In general, one name is used for the strata of each epoch although in recent years there has been a tendency to subdivide the formations so determined into two or more members. The name Tejon is a name which has rather wide application not only in this district but also in other districts. The name was first used by J. D. Whitney from the exposures in the vicinity of Fort Tejon in Kern County.

Oligocene rocks have been found in at least three of the oil fields of the district, but they have not always been differentiated from the Miocene rocks above. In the Coalinga field they are called the "Kreyenhagen formation." The Miocene rocks are best known and perhaps are the most consistent in lithologic character of any series. Much confusion exists at present regarding the correlation of the Miocene rocks and the nomenclature used in various parts of the district. The name Monterey is perhaps used most for the strata of Miocene age. Sometimes the basal portion of the Monterey is set apart as the Vaqueros because it is very sandy. In a number of the fields of the district the name Maricopa is used for the middle part of the Monterey and the name Santa Margarita for the upper portion of the Monterey. The very characteristic diatomaceous rock of the Miocene, which sometimes reaches a thickness of 5,000 feet, serves as a valuable reference horizon or key rock for correlation. The Pliocene rocks are usually divided into two or three members. In the Coalinga field the lowest member is the Jacalitos with the Etchegoin above it, and the Paso Robles making up the rest of the series. In the other field, the Jacalitos is not recognized, but the Etchegoin is generally differentiated as well as the Paso Robles. On the east side of the valley the Pliocene series is called the "Kern River series."

Producing Horizons.—It will be noted from a study of the geologic columns, in Fig. 213, that most of the oil in the San Joaquin Valley district comes from rocks of Pliocene or Miocene age. A little oil is found in the upper part of the Cretaceous in the Coalinga field. The principal production in this field, how-

ever, is from the basal Miocene, the Vaqueros sands. Farther south in the Lost Hills-Belridge field oil is found in the Maricopa shale of Miocene age and also in the Paso Robles member of the McKittrick formation, of Pliocene age. In the McKittrick field the bulk of the oil has been secured in the McKittrick formation.

Rocks of the same age as the McKittrick formation in the Midway-Sunset field are called the "Etchegoin formation" and furnish most of the oil in that field. Some oil has been encountered at lower stratigraphic levels there in rocks of Miocene age, the Santa Margarita and Maricopa formations. In the Wheeler Ridge field at the southern end of the district, the Etchegoin is also the producing horizon. Finally, along the western side of the valley in the Kern River pool strata of Pliocene age, the Kern River formation, and strata of upper Miocene age have furnished the bulk of the oil.

The oil occurs in sandy layers which are interstratified with shales. As a general rule, the individual layers of sand are thin and average perhaps 10 to 15 feet over the whole district. Often such sands are closely spaced in the section and make up a rather thick zone in which the oil is found. The lower zone in the McKittrick field, for instance, is sometimes 240 feet thick. They are thickest in the Kern River field, where as much as 500 feet of productive sand is found in some wells.

Relation of Production to Structure.—The oil in the San Joaquin Valley district has accumulated in anticlines and monoclines. In the anticlines it has been trapped under the well-known conditions set forth in the anticlinal theory of I. C. White. In the monoclines, it has been trapped largely because of the tarrification of the oil and the consequent sealing up of the sands at the outcrop. The hardening of the oil may be due to the addition of sulphur derived from the sulphate-bearing surface waters. It has also been suggested that the greater viscosity may be caused by reaction with alkaline waters or simply by fractionation. No doubt much of the oil found on monoclines has been trapped by the pinching out of the sand up the dip.

A somewhat exceptional condition is shown in Fig. 214 where the oil sands abut against an unconformity. In this instance the migration of the oil took place along the unconformity. When it reached the very porous sandy layers migration through them was easier than the movement along the unconformity and the sand

was saturated for a certain distance. This sequence of events is verified by the presence of water beyond the point where it contains oil.

Coalinga.—The Coalinga field is the northernmost field in the district. It covers an area 14 miles long and over 3 miles wide. The rocks are only slightly consolidated and rather intricately folded. Two pools are present, the East Side and the West Side pools. In the East Side pool, the oil occurs on an anticline which plunges toward the southeast and is open toward the northwest. Both flanks of the anticline are productive. In

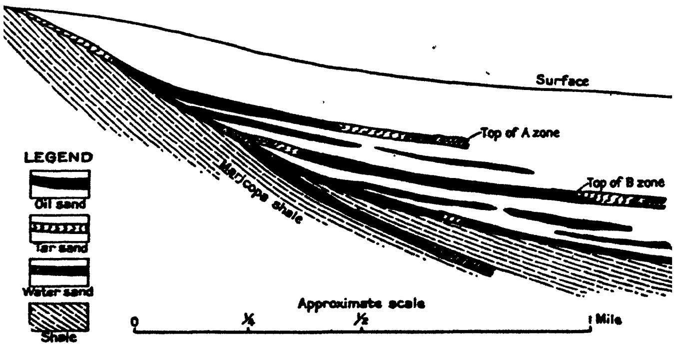

FIG. 214.—Diagram illustrating probable occurrences of water, oil, and tar sand in part of Sunset-Midway oil field, California. Arrows indicate direction of movement of edge water. (*After Pack.*)

the West Side pool, the oil occurs on the west flank of the Coalinga syncline near the west end. The outcrop of the sands on the surface is sealed by asphalt. The oil is found in five different horizons ranging from the Chico to the Jacalitos. The position of these five horizons is shown in Fig. 213 which is a generalized geological section for the whole Coalinga area. Most of the oil comes from three zones in the Vaqueros sandstone. It will be noted that the diatomaceous shales so characteristic of the Miocene series are conspicuous by their absence. Instead there is a diatomaceous formation below the Vaqueros (Kreyenhagen formation) which is thought by some to be the original source rock of the petroleum.

Belridge-Lost Hills Field.—Fifty miles south of the Coalinga field lie two pools which have a great deal in common and will therefore be treated as one field. The northern one is the Lost

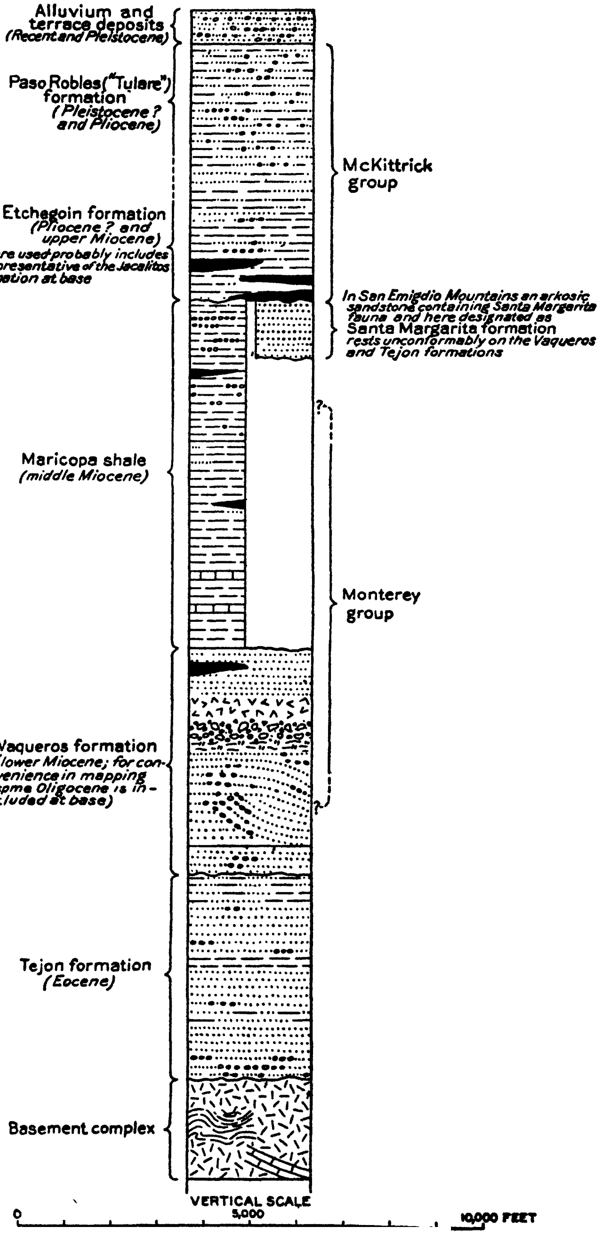

FIG. 215.—Generalized columnar section of the rocks in the Midway-Sunset oil field. Position of the oil-bearing sands indicated by solid black. (*After Pack, U. S. Geol. Survey, Prof. Paper* 116.)

Hills pool and the southern one the Belridge pool. In this part of the district the Kreyenhagen diatomaceous shales so important in the Coalinga field have practically disappeared from the section as well as the thick mass of blue shale which capped the Vaqueros in that field (Santa Margarita). In place of the Santa Margarita shale, we find a diatomaceous shale zone called the Maricopa shale. The oil in the Lost Hills pool has accumulated

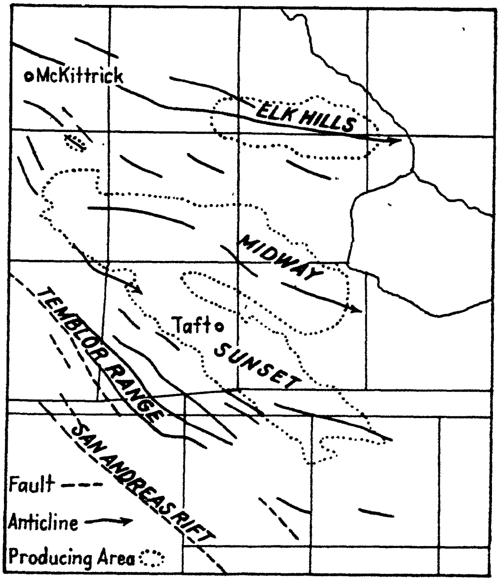

FIG. 216.—Geologic sketch map showing geologic structures of southwestern. Kern County. (*After Stalder, Oil and Gas Journal*, p. 46, Sept. 3, 1925.)

in a long narrow anticline which plunges gently toward the northwest and the southeast. The structure in the other pool is quite similar. The main production comes from the McKittrick formation and especially the Etchegoin member. Some oil has also been secured from the Maricopa shale.

McKittrick Field.—The McKittrick field lies scarcely 10 miles south of the Belridge pool. It is somewhat remarkable for the fact that the Franciscan, Cretaceous, Eocene, and Oligocene rocks are missing. The structural conditions under which the oil occurs are not well understood. On the north end of the pool Arnold and Anderson believed that the McKittrick formation had been underthrust. This interpretation is questioned by

English[1] who believes that the structure is not simply due to an overthrust fault and that this pool should not be used as an example of such a structural condition to explain the occurrence of oil (see Fig. 211, p. 569).

Midway-Sunset Field.—The producing area in the Midway-Sunset field is shown in Fig. 216 which also shows the Buena Vista and Elk Hills pools. It will be noted that the producing areas do not correspond entirely to the areas in which anticlines are shown. In fact, most of the production in the Midway-Sunset pools is monoclinal or on the flank of the Midway Valley syncline. The Thirty-five anticline shown near the town of Maricopa does not appear on the surface but has been worked out from well logs. The production in the Elk Hills pool seems to be on an anticline. The stratigraphic section for these three pools is similar to that for the McKittrick pool (see Fig. 215) except that the thicknesses of the formations are greater. The oil occurs in the Etchegoin formation mostly, but some is also found below it in the Miocene rocks. Some of the irregularities in the relations between production and structure are explained by Pack (see Fig. 214) as due to the overlap of the sands in the Etchegoin on the Maricopa shale.

Wheeler Ridge Pool.—The Wheeler Ridge pool lies at the southern extremity of the valley and is the most recently discovered pool (excepting the Kettleman Hills pool). It was opened up in 1923 and has produced on an average 1,000 barrels per day since the second year. The geologic column shows 2,500 feet of Maricopa shale, 3,000 feet of Oligocene rocks and about 3,000 feet of Eocene rocks. The oil horizon appears to be the Etchegoin in the basal part and also in the Maricopa shale. The structural conditions were described by Cunningham[1] as an asymmetric fold which trends N. 10° W. and plunges to the east. The dips on the north side are from 70 to 80° and only 10 to 12° on the south side. On the south side a strike fault has been noted. The producing area is located on the crest of the anticline.

Kern River Pool.—The Kern River pool is unique in a number of respects. It is the only important pool on the west side of the valley (Fig. 217). The producing area is nearly round and the strata are tilted about 3 degrees toward the southwest. Many

[1] See Bibliography.

believe the strata in which the oil occurs were laid down as a delta deposit or a huge alluvial fan. The water which is obtained from many wells is fresh. This may be due to artesian water conditions inasmuch as the Kern River flows across the unconsolidated beds about where they should crop out on the surface. The producing horizon is close to the contact between the Pliocene and the Miocene and is very thick. In some wells, 600 feet of oil sand has been encountered.

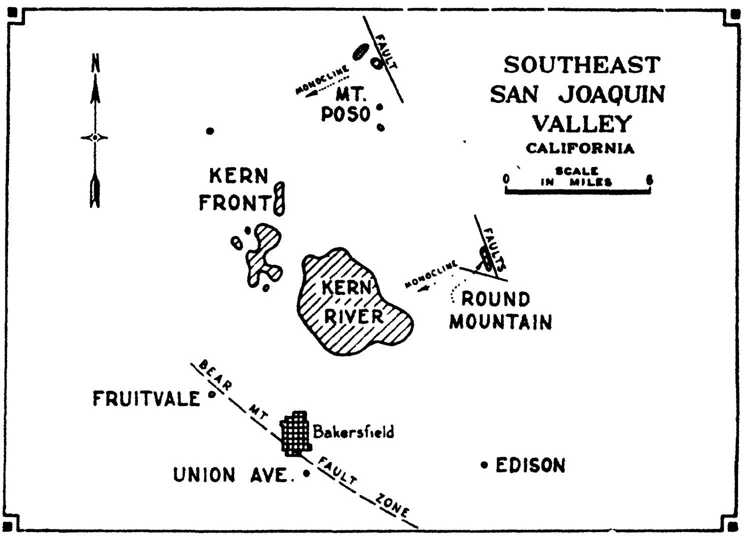

FIG. 217.—Kern River and new pools recently discovered. (*After Cadle, Bull. A.A.P.G.*, **12**, 657, Fig. 4.)

Production Statistics.—The fields in the San Joaquin Valley reached their peak in 1919 when over 80,000,000 barrels of crude were produced. Since then the decline has been slow and at times somewhat artificial. At present, for instance, it is estimated that nearly 100,000 barrels per day are shut in because of unfavorable price conditions. The Midway-Sunset field takes the banner for maximum total production, up to the end of 1929, with a total of 688,000,000 barrels. Coalinga which has produced for the longest period has accounted for a total of 312,000,000 barrels. The largest per-acre production must be credited to the McKittrick field where the production, to date, is slightly over 40,000 barrels per acre. The most remarkable well in the district is the Lakeview Oil Company's well No. 1. This well

came in with a terrific pressure in March, 1910, and made 65,000 barrels of 20° gravity oil per day. Four years later, Lakeview No. 2 well came in for 50,000 barrels per day. Like many another oil-field romance, well No. 1 was started by a small oil company, which encountered so much difficulty in drilling the hole that they finally sold their holdings to the Union Oil Company. The latter spent 8 months and much money in straightening the hole, but were rewarded with the biggest gusher of oil ever drilled in California. It has produced over 9,000,000 barrels of oil and is still rated as a 10-barrel well.

The gravity of the oil produced in the district varies considerably, but most of it is rather low as compared to other provinces in the United States. At Coalinga the range is from 12 to 36° but most of it lies closer to the lower figure. In the Midway-Sunset field the range is from 11 to 30° and in the McKittrick field from 12 to 20° Bé. In the Lost Hills pool, the oil from the Santa Margarita averages about 35° Bé. while that from the Jacalitos formation has a gravity of only 18°. The oil secured in the Kern River pool is a heavy asphalt base oil which runs from 10 to 16° Bé.

Gas Production.—A gas field is something of a novelty in California; therefore, the first well of the Milham Exploration Company, Kern No. 1, created a sensation when it blew in on Aug. 4, 1927. It blew in with such force that the tools were hurled high into the air: the gas immediately ignited, and in a few minutes the steel derrick was reduced to a tangled mass of wreckage. On the third day, the well died and left a crater 7,000 feet square. Other wells have been drilled since, and they demonstrate the existence of a gas field of considerable potentialities. One well also found oil in commercial quantities of an unusually high gravity, for California. The relation of the Buttonwillow pool to the other pools of the valley is shown in Fig. 217. Because these wells are located on the alluvium-covered plain in the San Joaquin Valley, it is not possible to work out the structure from surface observations. Core drilling with a careful study of the microfauna in the cores, will be necessary to find similar pools in this district.

SANTA MARIA DISTRICT

Introduction.—The Santa Maria district is one of the coastal districts. Its position with reference to the other districts in the

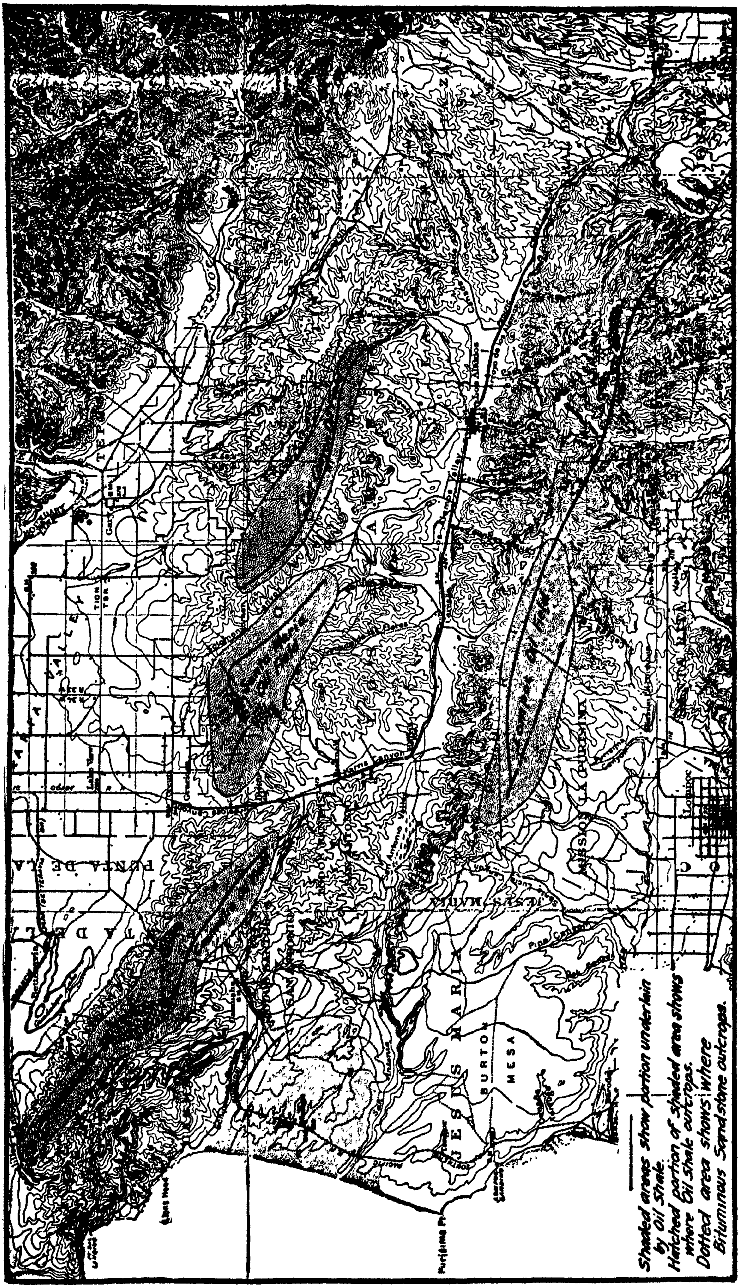

FIG. 218.—Oil pools of the Santa Maria district. (*After Gore, Bull. A.A.P.G.*, **8**, 462.)

state of California is shown on the map, Fig. 208, p. 560. The first successful oil well in this district was drilled in 1901. A well completed by the Pinal Oil Company on the north side of Graciosa Ridge was such a large producer that great interest was aroused in the possibilities of the district and many other wells were drilled. The Lampoc pool was opened in 1904 and the Arroyo Grande pool a year later.

The district covers an area of about 1,300 square miles all of which is located in Santa Barbara County. It includes portions of the Santa Ynez and San Rafael divisions of the Coast Ranges and especially the basin which lies between them. This basin is occupied by the Santa Maria, Los Alamos, and Santa Ynez valleys. In general, the region has the character of a triangular hilly basin opening out toward the coast between two divergent ranges of mountains. The distance between the mountains widens to 30 miles near the western side of the basin. In the basin two lines of hills and three valleys make prominent topographic features. The Solomon and Casmalia hills make up the northern line of hills, being separated from the San Rafael Mountains on the north border of the basin by the wide valley of the Santa Maria River. The Purisima Hills make up the southern line of hills, being separated from the Santa Ynez Mountains on the south border of the basin by the Santa Ynez River. This district began producing oil in 1902 and, up to the end of the year year 1929, had accounted for over 125,000,000 barrels of oil.

Tectonics.—The San Rafael Mountains, which delimit the productive area on the north, trend N. 50° W., approximately parallel with the general course of the structural lines in this part of California. The range thus makes a large angle with the coast line. The Santa Ynez Mountains which form the corresponding southern boundary of the productive area trend practically east and west and thus determine the unusual direction of the coast line south of the range. The average width of the range is about 9 miles. At the eastern end of this range lies the focal or nodal point of the mountain ranges of western California. For there, the northwest-southeast lines of structure which are dominant in the major part of the state (as indicated by the Diablo Range, the most eastern range of the Coast Ranges which comes in from the northwest, and the San Gabriel Range which comes in from the southeast) is opposed by the east-west trend of the Santa Ynez Range. The Tehachapi Range, which comes

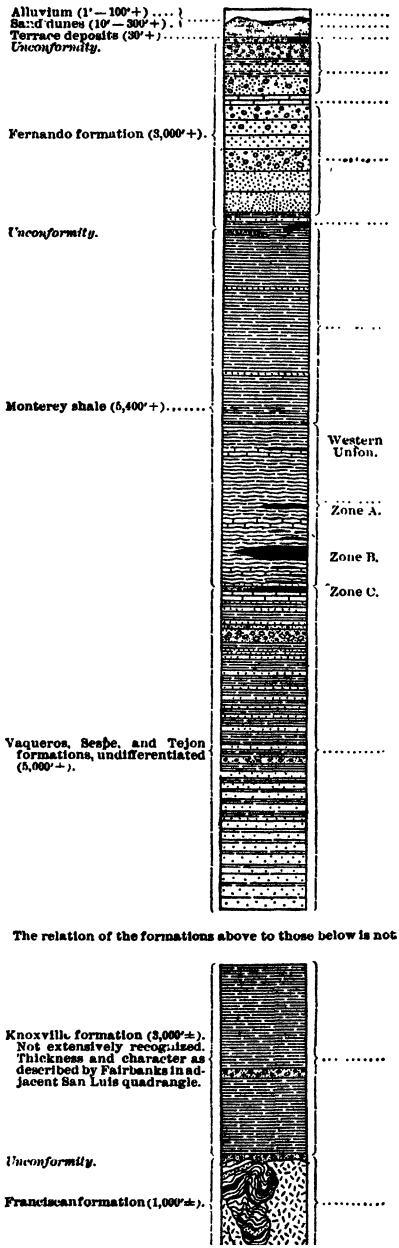

FIG. 219.—Columnar section of the sedimentary rocks of the Lampoc and Guadelupe quadrangles. (*After Arnold and Anderson, U. S. Geol. Survey Bull. 322, Pl. II, opp. p. 26.*)

in to this point from the northeast, serves as a connecting link between the Coast Ranges and the Sierra Nevada Mountains.

The valley between the two mountain ranges described is a structural syncline or synclinorium. In it the subordinate structural features are quite clearly reflected in the topography. For example, the larger valleys mark the synclinal axes of the broad lines of structure and the lines of hills mark the anticlinal zones. An illustration of an anticlinal zone is the line of the Purisima Hills and an example of a synclinal valley is the Santa Ynez River Valley with its structural continuation in the Santa Rita Valley.

Stratigraphy.—In this district a fairly complete section of the rocks characteristic of the province as a whole may be studied. The Franciscan rocks of probable Jurassic age are succeeded by the Knoxville formation of Cretaceous age. These, in turn, are followed upward by a complete representation of the various series of the Tertiary system, the Eocene, Oligocene, Miocene, and Pliocene. Rocks of the Pleistocene and Quaternary ages form the surface covering over a considerable portion of the district. These are shown in diagrammatic form in Fig. 219.

The oldest rocks in the district are believed to be the same as the rocks which form the basement of the sedimentary succession in the Coast Ranges and, known as the "Franciscan" farther north. They consist of sandstones, shales, glaucophane schist, and jasper associated with serpentine of intrusive origin. These sediments are very much disturbed and crop out in the mountains. The Knoxville formation is also found in the mountains in small isolated patches. It consists chiefly of dark-colored argillaceous shale.

The *Tejon* formation which is the oldest Tertiary formation crops out in the Santa Ynez Range and there grades without interruption into the Vaqueros formation of Miocene age. The series consists of alternating beds of dark shale and sandstone. In the upper portion there are some limestones, which are frequently massive, as well as some beds of fine and coarse conglomerates. Above the *Vaqueros* member of the Miocene series the typical organic shales so characteristic of California are found. This part of the section corresponds to the *Monterey* shale which was first described by Blake, in 1855, so called from the town of Monterey in central California. In the district under discussion the Monterey formation is divisible into two parts on a lithologic

basis: The lower half is composed chiefly of hard, metamorphosed, flinty shales, while the upper half is composed of soft shale which resembles chalk, but is of siliceous, instead of calcareous, composition. The hard shales in the lower division seem to be very bituminous. In the limy layers a bituminous odor is usually to be noted and often pockets of tar occur. In the flinty layers the oil occurs in crevices or in small cavities. The principal oil horizons in the developed pools belong in this part of the stratigraphic section. For that reason, the diatoms in the shale are looked upon by many as the original source of the oil.

An examination of the soft unaltered shale with a hand lens reveals innumerable small round dots ranging from 1 to about 1/10 millimeter in size. They are the skeletons of diatoms, a plant belonging to the lowest division of the plant kingdom, the Thallophyta, in which there is no differentiation of organs such as stems and leaves. These microscopic, one-celled plants are inclosed in two valves one of which overlaps the other. The cell wall is impregnated with silica and hence forms a resistant skeleton. In some parts of the deposit, the tests are remarkably well preserved, but, in other parts, they are largely broken or crushed and almost unrecognizable. The shale is soft and white and may easily be rubbed to a powder-like flour. The foraminifera, which make up a considerable portion of the Monterey shale elsewhere, seem to be lacking in this district, at least in the siliceous shale. The limestones and calcareous shales of the formation contain foraminifera.

The Monterey formation has nowhere been left undisturbed. At most places where it may be studied it is profoundly folded and the folds are so sharp and closely spaced that the succession of the beds and thickness of the formation is difficult to determine. Each of the two parts of the formation appears to be at least 2,600 feet thick, making a total of over 5,200 feet. The age of the formation is based chiefly on the fossils found in the Vaqueros which are of lower Miocene age, and the fossils found in the rocks at or near the base of the overlying Fernando formation, which are of upper Miocene age.

An interesting observation which has been made on the Monterey shale at many different points in the Santa Maria district is the fact that the shale has been burned. This is indicated by large sections of the shale which are pink or deep red

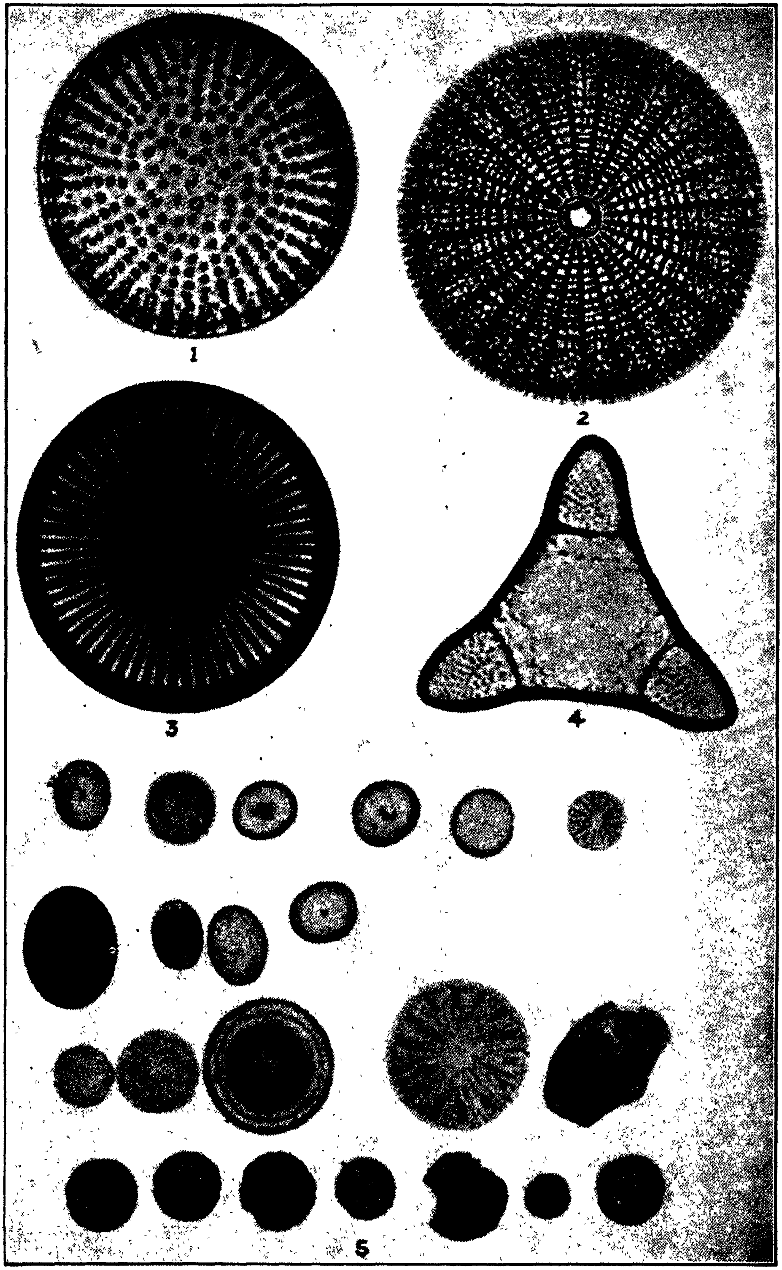

FIG. 220.—Monterey diatoms. (*After Arnold, U. S. Geol. Survey Bull.* 322, Pl. XIX.)

in color and which have been turned into a hard, vesicular rock, like vesicular volcanic rock. This alteration suggests that the shale has been pretty highly charged with bituminous matter. In the report of Arnold and Anderson a number of localities are mentioned which were burning at the time of their examination of the region. At one such locality small amounts of oil were oozing up at points near by and the ground was heated near all the seepages. Besides being present at the surface, such burnt shale was also noted in drilling and has been found as deep as 1,000 feet in the wells.

The *Fernando* formation as identified in the Santa Maria district comprises rocks of possible Miocene age as well as Pliocene and lowest Pleistocene ages. The name Fernando was given by Homer Hamlin to a series of rocks overlying the Monterey in the San Fernando valley of Los Angeles County. Similar rocks in a similar stratigraphic position are present in the Santa Maria district. They consist of sandstone, conglomerate, and shale resting with a more or less pronounced unconformity upon the Monterey formation. The thickness of the formation is at least 3,000 feet although the total is nowhere fully exposed. The unconformity between the Fernando and the Monterey is quite apparent around the periphery of the basin for there late Miocene orogenic movements were most marked. In the inner portion of the basin the unconformity is only slightly developed and both formations show very nearly the same amount of deformation.

The importance of the Fernando formation lies in the fact that it forms the oil horizon in some parts of the district. In addition, it is useful because it reveals the structure of the underlying Monterey where the latter formation contains the oil. Asphalt deposits of economic value have been found in the formation within the district and such accumulations of asphalt may point the way to further small pools of oil.

Near the bottom of the formation, soft, diatomaceous, or gritty shale is rather common. Most of the formation is composed of rather loosely consolidated, fine, white and yellow sand and coarser grey sand which grades locally into thick beds of loose conglomerate. Flint and hard shale embedded in a sandy matrix make up these conglomerates. Fresh-water limestone with a thickness of from 10 to 50 feet makes a rather conspicuous key zone in the formation about 1,000 feet above the base.

Producing Horizons.—The oil in the Santa Maria district has been trapped both in the Monterey shale and in the Fernando formation. In the former, the oil appears to come from sandy layers in the lower portion of the formation, as well as zones of fractured shale. In the Fernando formation, oil has accumulated in sandstones near the base.

Producing Fields.—Arnold and Anderson described two fields in this district in some detail—the Santa Maria and the Lampoc. Each of these consists of a number of small pools separated from each other by dry areas of small extent. The Santa Maria field lies between the Los Alamos and the Santa Maria valleys. It covers an area about 4 miles long by 3 miles wide. An anticline, called the Mount Salomon, forms the most prominent structural feature in the field and probably accounts for the presence of the oil. It is modified by subordinate anticlines and synclines as shown by a careful study of well logs. Four well-defined oil zones are present, two of which appear in every part of the field. They vary greatly in thickness, character, and composition from pool to pool. In one of the pools the first productive zone is penetrated at a depth of 1,600 to 2,100 feet, the variation being due to differences in geographic and structural position. In some wells 20 feet only are productive, whereas in other wells as much as 500 feet are productive. As usual, in California, this does not mean 500 feet of uninterrupted oil-saturated strata, but rather that the saturated strata are so close together and separated by thin barren zones in such a manner that the whole zone must be considered as a unit. In this first zone the hard porous shale as well as the softer and possibly more sandy layers contain oil. The second zone lies from 550 to 700 feet below the top of the first. In it also the hard shales yield oil as well as true sands interbedded with the shales. The third zone lies about 400 feet below the top of the second and appears to be the richest one of the three. In other respects it is similar to the others.

The *Lampoc* field lies on the flanks of the Purisima Hills. In these hills the topography mimics the structure rather closely, because the anticline, as revealed by the attitude of the rocks, coincides with the main axis of the hills. The subsurface anticline, as indicated by the wells which have been drilled, follows the trend of the surface anticline closely, but the axis is shifted slightly. Both have a steeply dipping northern flank and a low-

dipping, probably undulating, southern flank. An overthrust fault runs through the producing area and seems to have affected the accumulation of oil on the two sides to a certain extent. The wells penetrate from 40 to 800 feet of the Fernando formation, the difference in thickness being due to an unconformity at the base of the Fernando. In the Miocene shales, beneath, some oil has been found at shallow depths, but the main zone of saturation lies at a depth of from 2,200 to 4,100 feet. Limy shell layers at the top of this zone seem to have acted as a barrier to upward migration of the oil and the beds below these layers are very largely true sands. In the productive zone thin layers of oil-saturated shales and sands alternate with barren layers, but the total thickness of the zone may be as great as 1,100 feet in any one well.

The *Arroyo Grande* field lies in San Luis Obispo County a short distance north of the two fields described above. In this field the oil is derived from the basal sands in the Fernando formation into which it has migrated from the Miocene rocks below the Fernando. These Miocene rocks are greatly contorted and flexed and were eroded before the Fernando strata were deposited. The oil in the Fernando is, therefore, fossil seepage oil. This also explains the fact that the surface structure which is synclinal has probably had no influence on the accumulation of the oil in this field. The gravity of the oil also suggests migration from the Miocene for the oil tests only 14° Bé. whereas it tests about 25° in the Santa Maria and the Lampoc fields.

Relation of Structure to Production.—Considered in a general way the production of oil in this district may be said to coincide rather closely with anticlinal structure in the rocks. Some small pools and border areas are located in synclines or on the flanks of synclines. This may be due to concealed faults or to peculiar conditions in the reservoir rocks. The accumulation of oil in the Arroyo Grande field and adjacent pools is exceptional. There a surface syncline in the Fernando formation probably overlies a buried anticline in the Monterey formation, from which oil has escaped through long periods of time.

Production and Gravity.—In 1902, the Santa Maria district produced a little over 94,000 barrels of oil. Six years later, the crest of production was reached when nearly 9,000,000 barrels were produced. From 1908 to 1920, the production was fairly stable and fluctuated between 6,000,000, and 8,000,000 barrels.

After 1920, the production dropped off steadily until, in 1929, it barely reached 2,000,000 barrels. The district is not exhausted, however, and the future possibilities are still great. The gravity of the oil varies within rather wide limits. In the Arroyo Grande field the gravity is only 14° Bé., but in the fields farther south it runs higher. In the Lampoc field it ranges from 18 to 24° and in the other pools from 19 to as much as 35°. The average gravity is about 25°. Considerable quantities of natural gas accompany the oil and the pressure at first was very great.

In this district, asphalt has been produced on a commercial scale from the seepage areas in which the tar had accumulated on the surface. The asphalt occurs in three different ways: Some in veins in the Monterey shale and the later formations; much of it occurs as impregnations of the loosely consolidated materials overlying the Monterey; and, in some places, there are more or less pure masses on the surface where large quantities of oil issued from below and were hardened by contact with the air. A description of these deposits may be found in the *Twenty-second Annual Report* of the U. S. Geological Survey.[1]

The Ventura District.—The first wells in California were drilled in the southern part of Ventura County. The very large tar accumulations in the Ojai valley and on the sides of Sulphur Mountain early drew attention to the possibilities of this portion of the state. The first successful well was located not far from the town of Ventura and was completed about 1875, but it took nearly 15 years for production to reach a substantial scale. Many of the largest seepages appear to be associated with faults south of the Ojai valley and north of the Santa Clara Valley although at some places, as for instance, east of Sespe Creek, the oil seeps from the Monterey shales and the sandstones interbedded with them. Despite the fact that all of the early drilling was done close to these seepages no important pools were found, and in the really important areas seepages are scarce.

The tectonics of this part of California and the associated oil fields have been well described by Taliaferro.[2] In northern Ventura County three mountain ranges meet. The Coast Range element which trends from northwest to southeast (see Fig. 210, p. 565) is terminated somewhat abruptly by the east and west trending tectonic elements which assume prominence in this part

[1] ELDRIDGE, GEO. H., Pt. V, pp. 209–452, 1901.

[2] See Bibliography.

of the state. The Tehachapi Mountains which form the southern continuation of the Sierra Nevada Mountains form the southwestern portion of an arc which connects the Sierra Nevadas, trending nearly north and south, with the desert ranges, which trend nearly east and west. This conflicting set of trends is clearly reflected in the coastline of the state north and west of Ventura and Santa Barbara.

It seems natural, therefore, to find the topographic elements and the structural elements trending mostly east and west, rather than north and south. The San Andreas fault rift takes a course toward the southeast across the northern part of the county. Pitu and Sespe creeks flow from west to east for a considerable distance before they turn south at nearly a right angle. The Santa Clara River flows from east toward the southwest and is bounded on the north and on the south by structural elements which have a nearly parallel trend. Nevertheless, the structural conditions in Ventura County and in the region where the oil fields are located is decidedly complex. This is most prominently indicated by the thrust faults which have been found along the edge of the mountains and by the overturned folds which are to be seen at some places. These features are well shown in the valley of the Santa Clara River where at least two overthrusts have been mapped—the San Cayetano overthrust and the Santa Clara thrust. These thrusts are opposed to each other, the one to the north showing a displacement toward the south and the one to the south showing a displacement toward the north; in other words, the thrust is from the mountains toward the valley. The same holds for the Santa Susana thrust which shows a displacement toward the south away from the mountains toward the Simi valley. The plane of faulting is very low and almost horizontal (see Fig. 223, p. 603.)

The Santa Clara Valley, in a general way, is a syncline bounded by overthrusts, while the mountainous tracts north and south of the valley are anticlinal in structure. Thus in Oak Ridge and South Mountain, a number of domes and short anticlines have been worked out, all of which line up in a general way or form en-echelon series. Practically all the important oil fields so far discovered in the county lie on the high spots of this general line of uplift. Another similar line of uplift is located 6 or 7 miles south of it the Simi-Las Posas uplift, with a fault, Santa Rosa, south of it.

According to Taliaferro the diastrophic movements which were the cause of these structural conditions took place mostly during the Miocene epoch, and probably culminated at the close of the Miocene. Renewed movements took place along the same lines of weakness probably a number of times, but the structural network in its present aspect probably dates from the early Pliocene epoch, despite later Pleistocene movements.

Stratigraphy.—The oldest rocks in Ventura County are to be seen in the northeastern part of the county. They appear to be upper Paleozoic (?) schists intruded by granite of probable Jurassic age. These rocks are similar to those found in the Sierra Nevada Mountains with which they are also connected structurally. The Jurassic sediments, called the "Franciscan" formation farther north in the Coast ranges, have not been found within the county. The oldest sediments are the upper Cretaceous rocks found in the Simi Hills and the Santa Susana Mountains. They consist of sandstones and shales with a thickness of approximately 5,000 feet, and are correlated with the Chico formation (see Fig. 221).

The *Tertiary rocks* are naturally very important and are present in rather complete development. The earliest Tertiary rocks are called the "Martinez" formation and belong to the Eocene series. They are clastics and mostly sandstones and shales formed in marine waters. Their thickness amounts to about 2,500 feet. Above the Martinez strata is another marine formation consisting also of shales and sandstones with a similar thickness called the "Meganos" formation. A third Eocene formation —the Tejon—crops out in the county. It also consists of marine sediments including conglomerates, shales, and sandstones with a thickness of about 2,500 feet. In this formation the sandstones predominate over the shales.

The Oligocene series is probably represented by the Sespe formation. The type section for this formation lies north of Fillmore in Sespe Creek. It consists of shales, sandstone, and conglomerates, which, however, differ from the Eocene sediments because they are of fluviatile and lacustrine origin rather than marine. The thickness varies from about 4,000 to 6,000 feet. Because of the absence of fossils in the Sespe formation, its age has been determined from its stratigraphic position. It is exposed in the crests of the domes on Oak Ridge and South Mountain where the red, green, and maroon colors of the shales furnish a

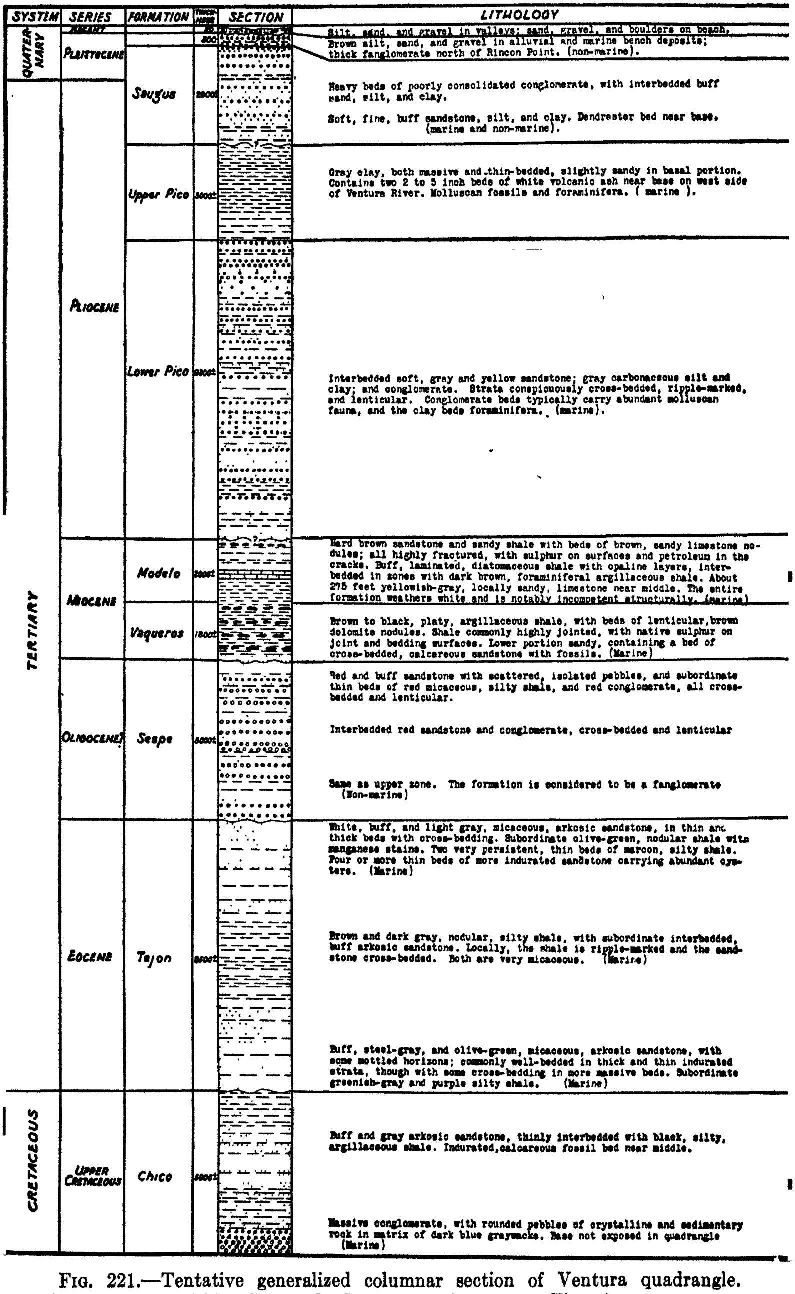

FIG. 221.—Tentative generalized columnar section of Ventura quadrangle. (*After Cartwright, Bull.* A.A.P.G., **12**, 239, Fig. 3.)

rapid index to their determination. Some oil has been found in the lower portion of the formation on these domes.

The *Miocene* strata furnish the thickest, most complex and most widely distributed series of rocks in the county. The thickness, and especially the complexity of the Miocene strata, is due to the inception of great orogenic movements during the epoch. Deep basins of sedimentation were formed between rapidly rising positive elements in the Pacific geosyncline. Hence, erosion was rapid and the basins were filled. During the early part of the epoch much sand was washed into the basins everywhere and, therefore, the lower portion consists of a thick sandstone formation called the "Vaqueros." Later, mud was washed into the central portions of the basins which had a marine character, and the coarser material accumulated nearer the existing shore lines. Hence, lateral variations are common and make for complexity. A characteristic type of sediment in the upper portion of the Miocene, the *Modelo* formation, is the diatomaceous shale. It is a soft, white chalky kind of sediment made up largely of the tests (diatoms) of small primitive plants. Within the diatomaceous shales are layers of cherty material and lenses of impure foraminiferal limestone. Another peculiar type of material in the Miocene part of the section is volcanic ash, basalt, and andesite. The enormous thickness of this kind of material, interbedded with the non-volcanic Miocene at some places in the county indicates that volcanoes must have been in eruption within the county at the time these sediments were laid down.

Resting unconformably upon the Miocene strata are shales, clays, and sandy shales which are always soft and easily eroded. These sediments belong to the *Pliocene* series and have been named the Fernando formation. The division of the Pliocene into the Pico and Saugus formations which has been done farther south in California appears to be impractical in the Ventura district, because of the similarity of the two divisions and the difficulty of tracing the unconformity between them. Some oil has been found in this formation, especially in the Ventura Avenue pool.

Oil Horizons and Source Beds.—Oil is obtained in the Ventura district from Eocene, Oligocene, Miocene, and Pliocene strata. The most important of these three series is the Oligocene. In seven, or about 50 per cent of the pools in this district, the oil

comes from the Sespe formation. Numerous, thin, extremely lenticular sands which are interbedded with the varicolored shales of the formation contain the petroleum. Two prominent zones are recognized in these fields, the upper one 550 feet thick and the lower one, lying 1,300 feet deeper, of similar thickness.

The fields which lie north of the San Cayetano fault obtain their oil from the Sespe formation chiefly, and subordinately from the Monterey and the Eocene. In the most important pool (the Modelo) the oil occurs in very thin sands in the Monterey formation. In the rather unimportant pools lying in the southern part of the county the oil occurs in various formations, but especially in the Sespe and the Tejon. A very interesting occurrence is that of the Conejo pool. There the petroleum has accumulated in a basalt agglomerate which lies at a depth of from 60 to 250 feet below the surface. One is led to suspect that this is seepage oil which has not been able to migrate farther toward the surface.

The only pool in which a large production is obtained from the Fernando formation is the *Ventura Avenue pool.* Only the lower portion of the Fernando, the Pico member, crops out on the crest of the anticline since the contact with the overlying Saugus member lies 3,000 feet (stratigraphically) higher than where drilling commences. Therefore, the total thickness of the Fernando in this part of the county is truly enormous and has been estimated at 25,000 feet or more. In the lower member of the Fernando where the oil occurs there are six different producing zones; the first being 1,300 feet thick and beginning at a depth of 300 feet from the surface. It consists of fairly loose sands and sandy shales. From 1,600 to 2,600 feet similar sands and sandy shales produced light oil in the early history of the field. Below this zone, lies 200 feet of loose sands and sandy shales which also produce a light gravity oil. The fourth zone appears below the only good lithologic marker in the field, the Gosnell shale zone, and is known as the "Upper Heavy Oil zone." It consists of 500 feet of sands and sandy shales. Immediately below this lies the Lower Heavy Oil zone with a similar lithologic character and about 800 feet thick. The sixth is called the "Lloyd zone" by Hertel[1] in a recent discussion of the Ventura Avenue pool. This zone is the deepest, the thickest, and the richest of the zones encountered up to date. It has a thickness of at least

[1] See Bibliography

2,350 feet and consists of sands and sandy shales, similar in every respect to the other zones previously described.

The *source rocks* for the oil in the various pools of the Ventura district have been the subject of considerable discussion and

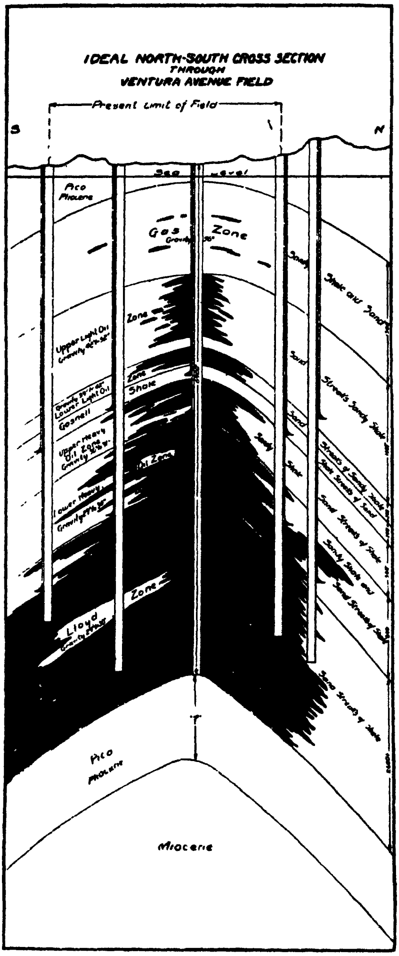

FIG. 222.—Oil zones in Ventura Avenue oil field. Depths shown in feet. (*After Hertel.*)

difference of opinion. Many have assumed that the Eocene strata have furnished the oil which is found in the Sespe, for the latter is not likely to be the original source on account of its non-marine nature and origin. Another suggestion, which has

appeared in print, is that the oil originated in the Monterey shales and migrated across the fault into the Sespe formation, which is overthrust over the younger formation north of Oak Ridge and South Mountain. The very apparent organic nature of the Miocene shales and their greater thickness make them appear a more probable source than the Eocene shales. The Miocene shales have also been suggested as the source of the very prolific production in the Ventura Avenue field from the Fernando formation. In this case, it seems more logical to assume that the oil has originated in the Fernando formation, although no convincing evidence is at hand.

Relation of Structure to Production.—In the Ventura district the relation between structure and production is very evident and very decidedly supports the orthodox anticlinal theory of accumulation. Fully 98 per cent of the present production comes from the crests of domes or anticlines. The remainder has been trapped by faults, some of which are small and local and some large and extensive, or by some more obscure type of trap on the limbs of large folds. The table below was prepared by Taliaferro[1] and shows not only the structure of each of the pools in the Ventura district, but also the producing formation:

Field	Formation	Structure
Ventura Avenue	Lower Fernando	Dome on anticline
South Mountain	Sespe	Dome
Montebello	Sespe	Dome
Torrey Canyon	Sespe	Dome
Bardsdale	Sespe	Dome
Modelo	Monterey	Plunging anticline
Simi	Sespe and Tejon	Plunging anticline
Scarab	Sespe	Limb of fold
Conejo	Basalt agglomerate	Fault
Sulphur Mountain	Monterey	Fault
Ojai	Monterey and Sespe (?)	Fault
Sespe Creek	Sespe	Fault
Hopper Canyon	Monterey	Sharp folds

The structure section which is shown in Fig. 223 presents a very good generalized picture of the structural conditions along a line nearly north and south from the Topatopa Mountains to the Conejo Mountains and the Pacific Ocean. It bisects the east

[1] See Bibliography

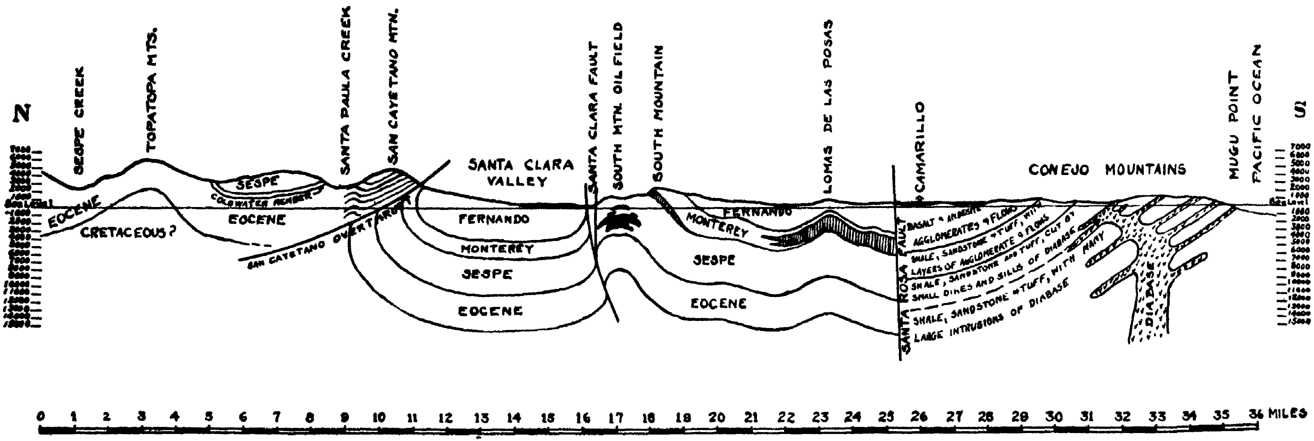

FIG. 223.—Structure section across the south-central part of Ventura County. (*After Taliaferro, Bull.* A.A.P.G., **8**, 804, Fig. 1.)

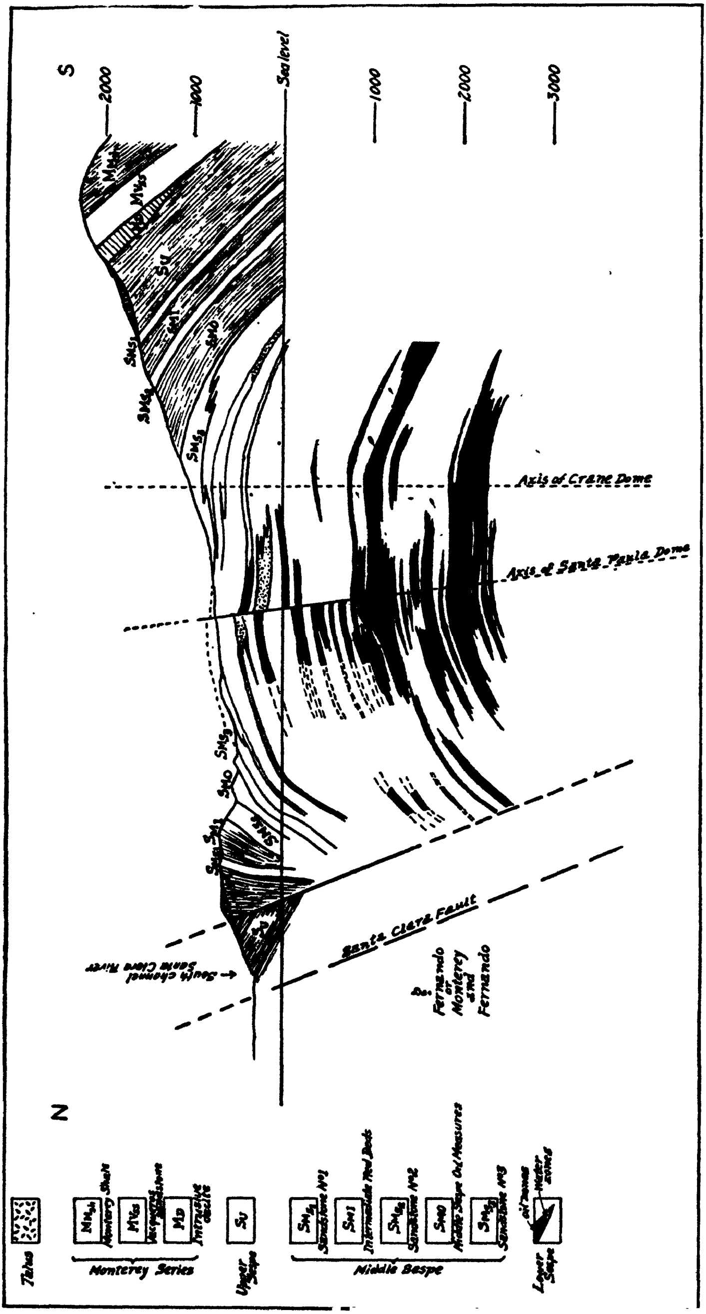

FIG. 224.—Structure section through South Mountain field. (*After Hudson, Bull. A.A.P.G.*, **8**, 818, Fig. 2.)

and west trending anticlines as well as the thrust faults. Figure 224 shows in somewhat greater detail the structure of one of the typical pools located on a dome along the main anticlinal zone of the district. In this particular case there is a tendency for the dome to show a double axis with depth which is probably due to a concealed fault. The width of this dome is about 2,000 feet on the crest and the length about 2 miles. On the north flank the dip increases gradually from 4 to 30° in the first quarter mile. Beyond this point the increase is more rapid until finally at a distance of 3,000 feet the beds are overturned, and dip south at a high angle. On the south flank the dip increases to a maximum of 60° in a distance of three quarters of a mile.

In the Modelo pool, which is the most important pool north of the San Cayetano thrust fault, the oil is obtained from an anticline with a very sharp crest. The south flank shows a dip of 55° and the north flank an average dip of 50°. So sharp is the fold that the producing strip along the crest is barely two locations wide.

Outstanding Pools.—The most remarkable pool in this district, and one of the most wonderful pools in the world for that matter, is the Ventura Avenue pool. The first oil well in California was drilled near one of the seepages in this pool, in 1866, and the seepages are among the largest in the United States. It is also remarkable for the enormous thickness of the producing zones, inasmuch as nearly all of the 6,700 feet of depth, which has been reached in some of the wells, can be called oil sand. The first zone is called the "Gas zone" and extends from 300 to 1,600 feet. This zone is no longer of importance, but at one time yielded gas and some small wells producing oil of 57° gravity. The Upper Light zone was capable of producing 150 barrels of 50° oil, but the salt water accompanying the oil made this zone unprofitable. The Lower Light Oil zone produced oil of 42° gravity, but it also has ceased to be a factor in the production records. The Upper Heavy Oil zone which lies just below the Gosnell shale is still capable of production, but is not used on account of the greater production at lower depths. The Lower Heavy Oil zone yields wells with initial production as high as 1,900 barrels per day of oil with a gravity of 30°. It is still relatively free from water. The lowest, deepest, and best oil zone is the Lloyd with a thickness of over 2,300 feet. Some wells in this zone have an initial production of 6,000 barrels per day accompanied by much gas (see Fig. 222, p. 601).

This field has the distinction of showing the second deepest oil production in the world and the base of the probable productive portion of the section has not been reached. The base of the Fernando formation has not been attained and some geologists believe that the Monterey formation (of Miocene age) is present below the Fernando, and that it also will produce oil. Great difficulties have retarded the development of the field. Tremendous gas pressures, which wrecked derricks and caused craters to form, turned aside early pioneers. Later, the heaving formations, at

FIG. 225.—View of Ventura Avenue oil field from south to north. (*After Hertel, Bull.* A.A.P.G., **12**, 723, Fig. 1.)

greater depths, which caused casing strings to become "frozen," put obstacles in the path of the producer. Engineering ingenuity finally overcame all of these difficulties. The topography is also very rugged and irregular making it necessary to build roads and to excavate for locations on a more expensive scale than elsewhere. In 1929, Ventura Avenue accounted for nearly 18,000,000 barrels of oil.

Another outstanding field in this district is the *South Mountain pool.* It is the youngest in point of age of the pools along the Oak Ridge anticlinal uplift area, the first producing well having been drilled in 1916. The Monterey formation of Miocene age and the Sespe formation of Oligocene age are the two formations exposed in and around the pool. The latter strata consist of sand-

stone, clayey sandstone, and shale over 6,000 feet thick, in which maroon and red colors are conspicuous. All the oil comes from sands in the Sespe formation (see Fig. 224) and the great thickness of the producing zone is remarkable, for it is not unusual to find as much as 1,800 feet of oil-saturated sand between the depths of 500 and 3,500 feet. The Monterey shales, which contain much organic matter, and in part are so high in hydrocarbons that they burn readily to a fused slag-like mass, do not seem to be important either as producing strata or as source rocks.

The structure of South Mountain is similar to that of the other four pools along the Oak Ridge-South Mountain anticlinal ridge. Each of these pools is located on a dome and they are arranged en echelon, each successive dome to the west lying farther south than its neighbor. The other domes, named from west to east, are the Bardsdale, Montebello, Wiley Canyon, and Torrey Canyon. Several small faults are known within the field, but none exceeding 50 feet in displacement. Others beyond the confines of the field are known with a greater displacement and it is probable that the subsurface conditions are partly controlled by faulting.

LOS ANGELES BASIN DISTRICT

The most interesting district at the present time is the Los Angeles Basin, partly because of the large number of truly remarkable pools, and partly because this district seems to furnish the best opportunities for further exploratory work. The location of the pools discovered up to date is shown in Fig. 226. This map also shows the areal geology of a large portion of the basin. The surface indications in the district are not so striking as they are in the other districts described. The only important seepage area is the one located west of Los Angeles and called the "Los Angeles Brea deposit." This is described in detail on page 561. A few seeps southeast of the Elysian Hills and in the Puente Hills are the only other surface indications known, except possibly the seepage of petroleum under the ocean west of Redondo. The line of contact between the Puente and the Pico formations is often characterised by an abundance of bituminous matter which is in the nature of fossil seepages.

Historical.—The earliest wells in the Los Angeles basin were drilled near the tar seepages west of the city of Los Angeles, about 1893. These wells were shallow and fairly good producers so that great activity was stimulated by them. The Salt Lake and the

Los Angeles City pools were quickly drilled up resulting in a period of overproduction. In 1897, Olinda and Fullerton in the northeastern part of the basin were discovered and reached their peak of production about 17 years later. Montebello began to produce oil in 1917, Coyote in 1918, Richfield and Santa Fé Springs in 1919, Huntington Beach in 1920, Long Beach in

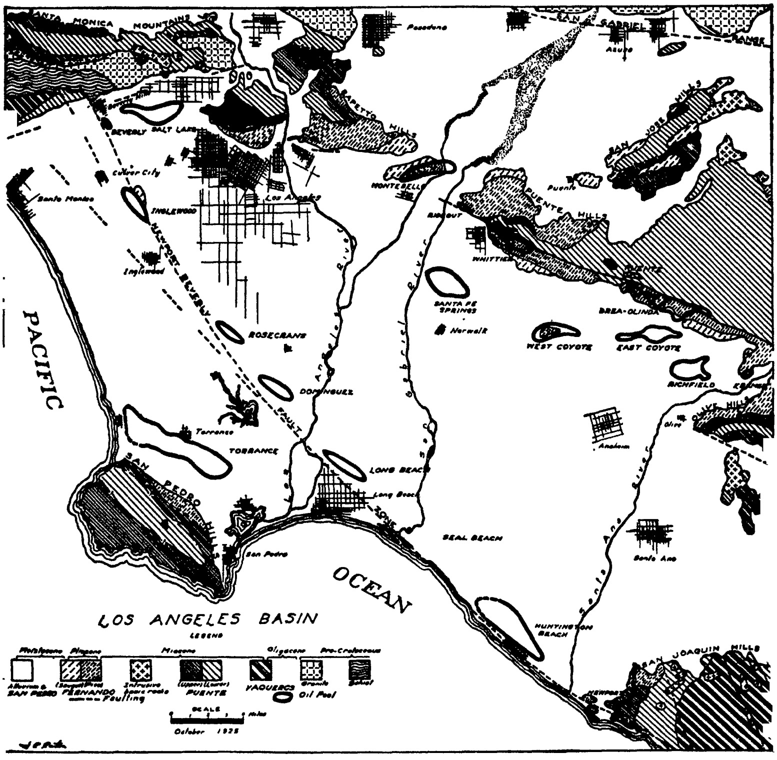

FIG 226—.Geology and oil developments of the Los Angeles basin. (*After Eaton, Bull.* A.A.P.G., **10**, 754, Fig. 1.)

1921, Huntington Beach and Torrance in 1922, Dominguez in 1923, Inglewood and Athens-Rosecrans in 1924, and Seal Beach in 1926. Some of these fields reached the peak of maximum daily production within a few years, because of an intensive drilling campaign, while others were developed more slowly. In some of them deeper zones of oil saturation were discovered and a revival took place. It will be noted from the map that the periphery of the basin has been pretty well tested. The central

portion of the basin may contain quite a number of good pools subject to future discovery.

Tectonics.—The Los Angeles basin occupies an area of about 1,000 square miles, bounded on the south and west by the Pacific Ocean, on the north and east by the Santa Monica, San Gabriel, and Santa Ana Mountains. It is regarded by Willis as a part of the California Coast Range province tectonically. In general it is a low, flat plain with occasional low northwest trending ridges of varying relief. These ridges are the topographical

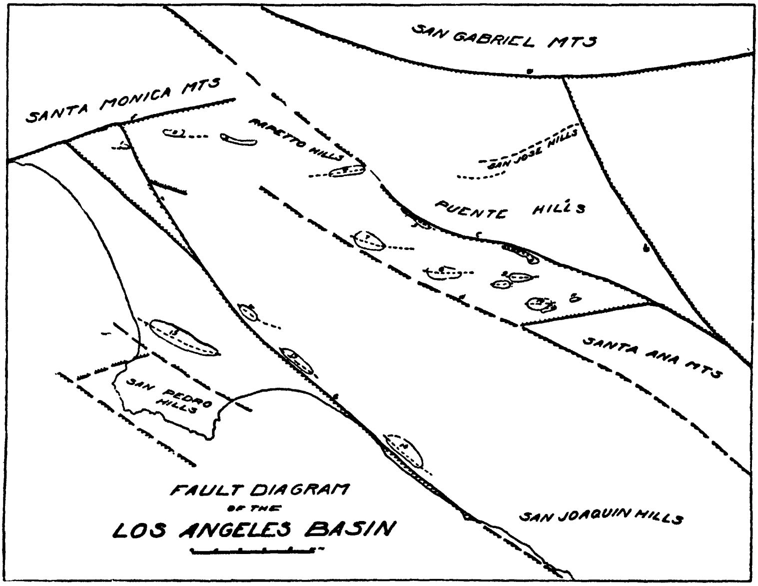

FIG. 227.—Fault diagram of the Los Angeles basin. (*After Ferguson and Willis Bull.* A.A.P G., **8**, 578, Fig. 1.)

expression of structural domes beneath showing that there is a rather close correspondence between rock structure and topography which is the case of many parts of this petroliferous province.

In order to explain the domes, Willis postulates horizontal movements in the basement rocks, beneath the Mesozoic and Cenozoic blanket of rocks. With one section of these relatively rigid and very massive rocks moving toward the northwest and the other section (lying on the northeast side) moving toward the southeast he believes folds arranged in an en-echelon manner will

be produced. This may be demonstrated by splitting a square piece of glass diagonally from corner to corner, pasting some thin cloth over the break and then moving the two segments in opposite directions. These primary shear lines and some of the resultant domes are shown in the Fig. 227.

Undoubtedly, movement along the shear lines took place frequently during Mesozoic and Cenozoic times. The age of the folds in the basin indicates that movement took place as late as Pliocene and even Pleistocene times. In addition to the folds, faults were also developed in the thick blanket of Tertiary rocks of the basin. Some of these faults, especially those on the north and east, seem to have a nearly vertical displacement. These faults are not easy to discover nor to trace, because of the loose unconsolidated nature of the Tertiary strata. Around the margin of the basin in the mountains and in the deeply dissected foothills numerous good outcrops make their detection possible, and in some cases the approximate displacement may be estimated. As a rule, however, they are difficult to trace even there. In the flat part of the basin, faults are doubtless also present, but their location and trend must be based on hypothetical considerations.

The domes which resulted from deep-seated movements in the massive rocks are often reflected in the topography. At Dominguez and Long Beach, for instance, elongated domes are present which closely imitate the subsurface structure. At Richfield and at Huntington Beach the indications are very slight. Only low faint bulges in the topography serve to mark the location of the very productive domes below.

Stratigraphy.—In the table below, a generalized stratigraphic column for the Los Angeles basin is presented. It is taken from Eaton's excellent article[1] and shows the succession of rocks from the oldest exposed strata up to, and including, the recent deposits.

Beginning with the oldest rocks the various formations and members are briefly described as follows: The dark schist, which is believed to be of *pre-Cretaceous* age, is exposed in the Santa Monica Mountains, on the north side of the basin. It is generally believed that it is of Paleozoic age, although some evidence has been presented to indicate that its age may be as recent as Jurassic. Into the schist, diorite, biotite and hornblende granites have been intruded. In the Santa Ana and the

[1] See Bibliography.

STRATIGRAPHIC COLUMN FOR THE LOS ANGELES BASIN

Series	Formation	Member	Thickness, feet	Lithology
Recent				Alluvium and terrace materials
Pleistocene	San Pedro		500	Sands and gravels
Pliocene	Fernando	Saugus	1,400	Conglomerates, sands, blue clays
		Pico	5,600	Sands and shales. Local conglomerates (chiefly marine)
Miocene	Monterey	Puente	3,200	Diatomaceous shales with local sandstones and thin limestones (marine). Intrusive basalt and diabase. Some heavy bedded sandstones
		Vaqueros	1,000	Coarse massive sandstones and local conglomerates
Oligocene (?)				
Pre-Cretaceous				Dark micaceous schist intruded by granite

Santa Monica Mountains, Cretaceous rocks are present, and also some older Tertiary rocks of Eocene and possibly Oligocene age. These rocks in all probability underlie the younger rocks of the basin, but up to date no rocks older than the Miocene have been reached by the drill. It is thought that the total thickness of the Tertiary strata from the Pleistocene to the base of the Miocene amounts to at least 11,000 feet. If the Eocene and Oligocene series are present it will be seen that the Tertiary system as a whole must have a very remarkable thickness.

The character of the Tertiary rocks is briefly indicated in the table above. It will be noted that clastic materials are chiefly involved, limestones being found only in the Miocene and then only in thin layers. Shales probably constitute the larger portion of the section, but sandstones are very numerous. Naturally, in an environment such as must have existed in California when these strata were deposited, any individual layers or even groups of layers cannot be expected to continue very far horizontally. Variations from conglomerates to sand-

stones, and finally to shales toward the center of the basin, are the rule. Nevertheless, there is a certain amount of uniformity to be detected when considerable thicknesses of strata are traced from one part of the basin to another. The lowest portion of the Miocene, for example, consists predominantly of massive sandstones. In places it has a thickness of 1,000 feet or more. This sandy phase of the Miocene has been named the Vaqueros member (formation) of the Monterey formation (group). Above the sandstones a very great thickness of diatomaceous shales are found. This part of the section is rather more distinctive than the other parts, because of the great abundance of diatom tests. It is called the "Puente member" (formation) in the Los Angeles basin from the type locality in the Puente Hills (see Fig. 220). There the formation is divisible into three members; the lower one consisting of argillaceous and siliceous shales, the middle one of heavy-bedded sandstones, separated by thin siliceous shales, and the uppermost one consisting of diatomaceous shales. Elsewhere in the basin these members cannot be differentiated, but the characteristics of the formation, as a whole, especially the presence of diatoms, serves to identify it.

The *Fernando* formation was named by Homer Hamlin from the outcrops of siliceous shales in the San Fernando Valley of Los Angeles County. Although the name was originally used in an unpublished manuscript, its standing was established by Eldridge, Arnold, Anderson, and other geologists. In 1924, Kew[1] divided the formation into two members; namely, the *Saugus* and the *Pico* on the basis of an unconformity. The character of this formation is quite variable from place to place, both in thickness and in character. It consists of sands, shales, clays, and conglomerates which have a thickness of over 7,000 feet in the Los Angeles basin. This compares with over 18,000 feet in Ventura County northwest of Santa Paula. As might be expected, the sediments are coarse near the mountains and finer toward the center of the basin, but, in addition to that, the upper member the Saugus consists of coarser materials than the Pico.

The *San Pedro* formation is distinguished from the underlying formations largely on the basis of an angular unconformity. Evidently, crustal movements took place on a large scale after Pliocene time, so that the strata of Miocene and Pliocene ages

[1] See Bibliography.

are deformed. The strata of San Pedro age are but slightly affected by crustal movements and still lie in nearly horizontal attitudes. Most of the Los Angeles basin is covered with a sheet of materials, chiefly sands and gravels, all of which are referred to the San Pedro formation. It varies in thickness from nothing to over 500 feet.

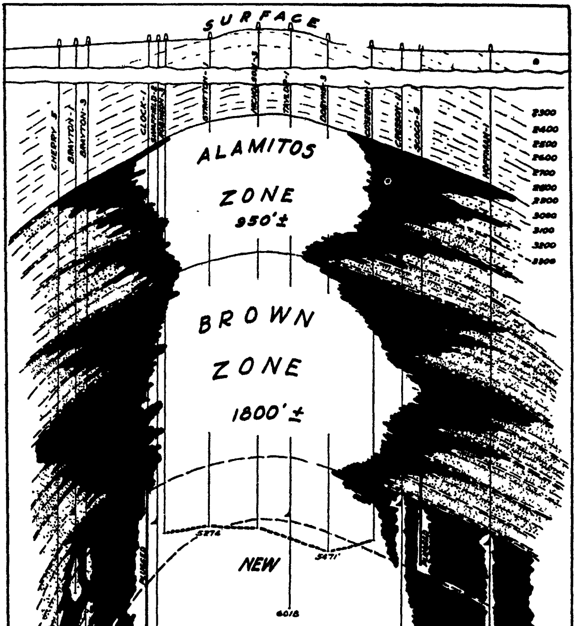

Fig. 228.—Cross-section through the Long Beach pool showing the thickness of the producing zones. (*After Jensen and Robertson, Bull.* A.A.P.G., **12**, 664.)

Producing Horizons.—One of the characteristics of the occurrence of petroleum in California is the great thickness of the oil saturated zones. The Los Angeles basin pools show this characteristic in a marked degree, for in some of them oil has been secured from thousands of feet of strata more or less continuously. Figure 228 shows the stratigraphic range of petroleum-bearing rocks in the Long Beach pool where oil occurs in commercial quantities throughout a thickness of over 4,000 feet.

In the course of drilling it has been found that the oil occurs both in the Pliocene and the Miocene rocks. Until the last few years most of the production came from the lower portion of the Pliocene series, from the basal part of the Pico member of the Fernando formation. In 1927 and 1928, a number of pools were drilled to deeper levels and large quantities of oil were found in Miocene rocks. This is true of the Richfield, Huntington Beach Townsite, Seal Beach, Long Beach, and Santa Fé Springs pools. Considering the fact that some of the early deep tests (as, for instance, some wells at Santa Fé Springs drilled to a depth of over 7,000 feet) failed to find the Miocene oil, it seems reasonable to expect that Miocene strata will be found productive in every pool before drilling is discontinued.

The producing horizons are not zones of pure sands or sandstones. Rather they consist of zones several hundred feet thick, in which thin sands, sandy shales, and shaly sands predominate over the shales or clays. Such oil-saturated zones are often separated by non-productive zones that are very similar in lithological character. Sometimes the intermediate zones contain water-bearing sands as is shown in Fig. 229. This is an ideal east to west cross-section through the Inglewood oil pool. It shows two prominent oil zones separated by sands which contain water now, although at first these sands also contained some oil.

Relation of Structure to Production.—In the pools of the Los Angeles basin the relation of structure to production is very evident. There are 19 important pools in the basin and in all, except possibly four, the oil occurs in a dome or a plunging anticline. A typical subsurface map of one of the pools is that of Dominguez.[1] In this pool the strata probably conform to the oil zone in attitude and, therefore, indicate an enlongated dome 12,000 feet long, and about 3,000 feet wide (taking only the productive area into consideration). All fields along the southwest side of the basin show similar subsurface conditions and all may be called domes. Of the pools on the northeast side of the basin all are domal or anticlinal except Los Angeles City, Brea-Olinda, and Whittier. These three are monoclinal and in them faulting has played a large part in trapping the oil.

The influence of faulting as a trap for migrating oil was shown in other provinces, as, for instance, in the Mexia and Balcones

[1] See Bibliography; Jensen and Robertson.

districts of the Mississippi Embayment province. There consolidated rocks and characteristic subsurface horizons make it possible to recognize the faults and determine the throw. In California this is not so easily determined, because of the lack of definitely traceable horizons. In the Brea-Olinda pool the long Puente fault, and some minor associated faults, seem to have exercised a controlling influence in trapping the oil as it migrated up the dip from southwest to northeast. No doubt, similar faults exist in many of the other pools, but because of the character of the sediments have not been recognized. Such a

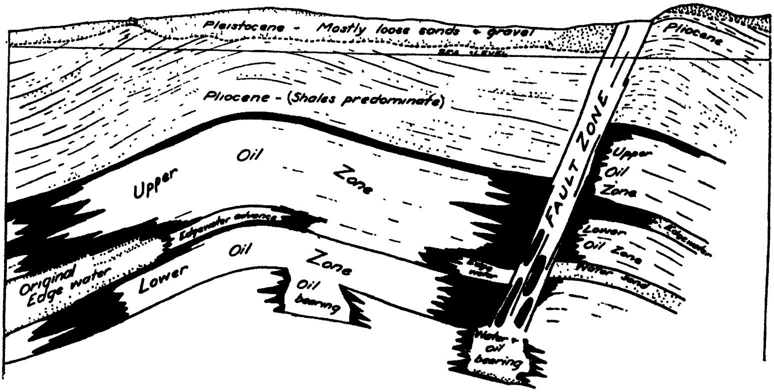

FIG. 229.—Ideal west-east section through the Inglewood oil field showing the relation of Pleistocene to Pliocene sediments and upper and lower oil sands with edge-water sands; also relation of fault to structure. (*After Jensen and Robertson, Bull.* A.A.P.G., **12**, 639, Fig. 7.)

fault, for instance, has been worked out from subsurface data for the Inglewood pool. The maximum displacement amounts to 450 feet but becomes much less toward the northwest and southeast. In this case oil has accumulated on both sides of the fault, which seems to indicate that faulting took place after the oil accumulation had taken place. This interpretation is also substantiated by the surface topography. For, on the northeast side of the fault the topography is high, and the lower topography to the southwest concealed the crest of the structure. Incidentally, the Baldwin Hills (as the high topographic region to the northeast is called) is the most prominent topographic feature in the whole string of pools.

Faults have been found on the north side of the Long Beach and the Seal Beach pools as well as on the south side of the main

Huntington Beach pool. The latter fault breaks the dome in such a way that the main part of the field appears to be on a monocline. The rest of the pool which lies a short distance toward the southwest is often referred to as the Townsite pool or the Barley Flat pool. Another interesting feature of the Huntington Beach field is the fact that the production of the main pool (northeast of the fault) is from Pliocene strata while the produc tion from the Townsite pool, or at least a large portion of it,

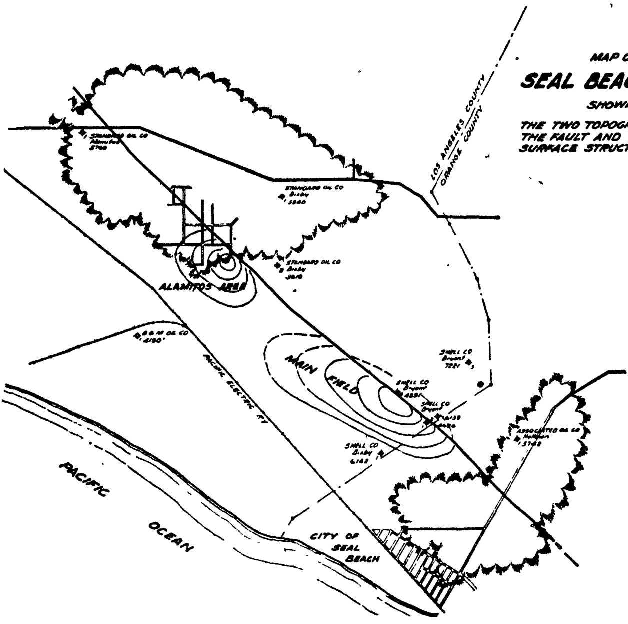

FIG. 230.—Map of Seal Beach. The wells shown were the test wells drilled before the field was discovered. (*After Jensen and Robertson, Bull.* A.A.P.G., **12**, 641, Fig. 9.)

comes from Miocene strata. From this it is inferred that the area to the northeast is on the downthrow side.

In the Seal Beach field the downthrow side is also on the northeast side. Figure 230 shows the relation of the fault to the two producing pools in the Seal Beach field. It also shows the early test wells which were drilled on the strength of the topographic features near Seal Beach. The finding of two independent pools on two different domes is interesting.

Production Data.—While the individual pools of the Los Angeles basin are not small pools as compared to those of other

petroliferous districts, yet they cannot be considered large. Most of them average about 1,500 acres in area. The pool which has the largest proven area at present is the Torrance pool with about 4,500 acres, while the smallest fully developed pool is the Whittier pool with 903 acres. The production from these pools has been much larger than might have been expected. Inasmuch as none of the pools is entirely exhausted, final figures for the production on a per-acre basis cannot be given. The preliminary figures indicate that the per-acre production will be larger than that of any other district in the United States. Up to the end of 1929, the Long Beach pool had produced 382,000,000 barrels from 1,300 acres which means over 200,000 barrels per acre. A number of the pools have already produced over 100,000 barrels per acre, among which are the Santa Fé Springs and Coyote. The table below gives a summary of production statistics and other information relative to the pools in the basin.

DATA REGARDING POOLS IN LOS ANGELES BASIN

<table>
<tr><th>Pool</th><th>Structure</th><th>Productive area</th><th>Gravity, degrees, Baumé</th><th>Total production, barrels, to Jan. 31, 1930</th></tr>
<tr><td>Salt Lake</td><td>Anticline</td><td>1,300</td><td>10 to 23</td><td rowspan="2">62,599,196</td></tr>
<tr><td>Los Angeles</td><td>Monocline</td><td>110</td><td>14 to 19</td></tr>
<tr><td>Montebello</td><td>Dome</td><td>1,175</td><td>19 to 30</td><td>84,069,000</td></tr>
<tr><td>Whittier</td><td>Monocline</td><td>900</td><td>14 to 23</td><td>14,124,000</td></tr>
<tr><td>Santa Fé Springs</td><td>Dome</td><td>1,600</td><td>24 to 36</td><td>266,866,000</td></tr>
<tr><td>Coyote</td><td>Anticline</td><td>2,100</td><td>14 to 30</td><td>120,682,000</td></tr>
<tr><td>Olinda</td><td>Monocline faulted</td><td>1,500</td><td>16 to 25</td><td rowspan="2">133,219,000</td></tr>
<tr><td>Fullerton</td><td>Domal</td><td>1,600</td><td>15 to 25</td></tr>
<tr><td>Richfield</td><td>Domal</td><td>1,275</td><td>15 to 25</td><td>61,420,000</td></tr>
<tr><td>Beverly Hills</td><td>Dome</td><td>84</td><td>12 to 16</td><td></td></tr>
<tr><td>Inglewood</td><td>Dome</td><td>870</td><td>14 to 29</td><td>68,713,000</td></tr>
<tr><td>Athens-Rosecrans</td><td>Domes</td><td>700</td><td>32 to 43</td><td>22,567,000</td></tr>
<tr><td>Dominguez</td><td>Dome</td><td>1,000</td><td>26 to 35</td><td>42,194,000</td></tr>
<tr><td>Long Beach</td><td>Dome</td><td>1,650</td><td>21 to 31</td><td>386,476,000</td></tr>
<tr><td>Seal Beach</td><td>Faulted dome</td><td>1,000</td><td>23 to 29</td><td>44,797,000</td></tr>
<tr><td>Huntington Beach</td><td>Dome</td><td>2,750</td><td>17 to 28</td><td>163,834,000</td></tr>
<tr><td>Newport</td><td>Dome (?)</td><td>100</td><td></td><td>107,835</td></tr>
<tr><td>Torrance</td><td>Anticline</td><td>5,000</td><td>11 to 28</td><td>64,627,000</td></tr>
</table>

Future Prospects.—Undoubtedly other pools will be discovered in the Los Angeles basin in the future. A most likely locality for a big pool is the Potrero area between the Inglewood and Rosecrans pools. The natural assumption that the best pools will be located around the periphery of the basin, as is the case in so many of the districts of the Rocky Mountain geosyncline province, may hold true in the Los Angeles basin also. Nevertheless, the Santa Fé Springs pool suggests that some very important exceptions may be found.

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INDEX

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